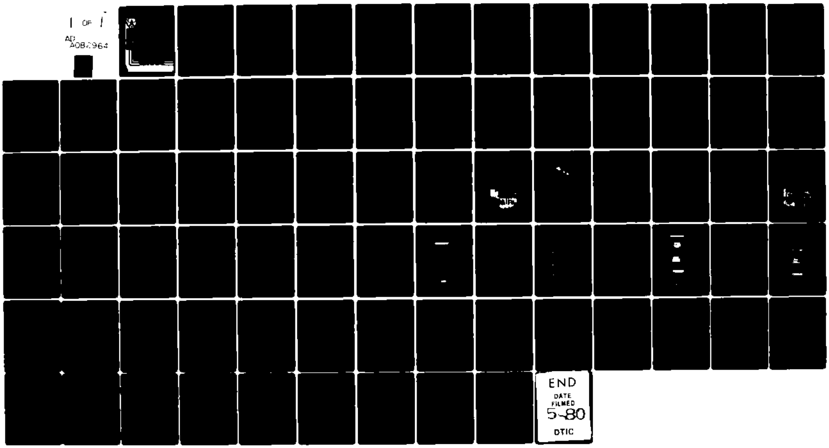
AD-A082 964 ARMY AEROMEDICAL RESEARCH LAB FORT RUCKER AL F/G 6/17
A FIRE SIMULATOR/SHUTTER SYSTEM FOR TESTING PROTECTIVE FABRICS --ETC(U)
MAR 79 F S KNOX, P W SAUERMILCH, T L WACHTEL
UNCLASSIFIED USAARL-79-4 NL



LEVEL II

USAARL REPORT NO. 79-4

A FIRE SIMULATOR/SHUTTER SYSTEM FOR TESTING PROTECTIVE FABRICS AND CALIBRATING THERMAL SENSORS

ADA082964

by

F. S. Knox III

P. W. Sauermilch

T. L. Wachtel

G. R. McCahan, Jr.

W. P. Trevethan

C. B. Lum

R. J. Brown

L. A. Alford

March 1979

U.S. ARMY AEROMEDICAL RESEARCH LABORATORY
FORT RUCKER, ALABAMA 36362

USAARL

NOTICE

Qualified Requesters

Qualified requesters may obtain copies from the Defense Documentation Center (DDC), Cameron Station, Alexandria, Virginia. Orders will be expedited if placed through the librarian or other person designated to request documents from DDC.

Change of Address

Organizations receiving reports from the U. S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding abo t laboratory reports.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Reviewed:

Stanley C. Knapp

STANLEY C. KNAPP
Colonel, MC
Commanding

David D. Glick

DAVID D. GLICK, LTC, MSC
Chairman, Scientific Review Committee

Released for Publication:

Stanley C. Knapp

STANLEY C. KNAPP, COL, MC
Commanding

14 USAARL-79-4

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
USAARL Report No. 79-4

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
9

4. TITLE (and Subtitle)
6
A FIRE SIMULATOR/SHUTTER SYSTEM FOR TESTING PROTECTIVE FABRICS AND CALIBRATING THERMAL SENSORS

5. TYPE OF REPORT & PERIOD COVERED
Final Report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10
S. Knox III; P. W. Sauermilch; T. L. Wachtel; G. R. McCahan, Jr.; W. P. Trevethan; C. B. Lum; R. J. Brown; and L. A. Alford
Franc[illegible]

8. CONTRACT OR GRANT NUMBER(s)
12 77

9. PERFORMING ORGANIZATION NAME AND ADDRESS
US Army Aeromedical Research Laboratory
P. O. Box 577
Fort Rucker, AL 36362

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
16
6.27.73.A, 3E762173A819, 015

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Medical Research & Development Command
Fort Detrick
Frederick, MD 21701

12. REPORT DATE
11 Mar[illegible]979

13. NUMBER OF PAGES
74

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This document has been approved for public release and sale; its distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Postcrash Fire
Fire Simulator
Porcine Burn
Bioassay Methods
Fabric Test Methods
Thermally Protective Clothing
Thermal Sensor Calibration

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See back of form.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

JCB

404571

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT

The design, construction, calibration, and use of a JP-4 fueled, shuttered furnace is described. Based on a NASA design, this furnace simulates the radiative and convective thermal environment of a postcrash fire in rotary-wing aircraft. Heat fluxes ranged from 0.5 to 3.6 ±3% calories per square centimeter per second with steady-state furnace wall temperatures from 519°C (967°F) to 1353°C (2450°F) and a radiative/total flux ratio of approximately 0.9. A pneumatically propelled, water cooled shutter, mounted in a rolling animal carrier, controlled the exposure of pigs and thermal sensors to the fire. An electronic data acquisition and control system is also described. This system automatically controlled the opening and closing of the shutter and provided strip chart and FM magnetic tape records of exposure time, furnace wall temperature, heat flux, and sensor output. Sources of error including nonuniformity of flame front and shutter dynamics are discussed. Methods of animal handling, burn grading, and photographic documentation are introduced along with a brief description of some nine experimental protocols carried out using this fire simulator shutter system.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

FOREWORD

The Thermal Project was a study designed to establish the correlation between thermal parameters measured by physical sensors and the damage to animal tissue when both physical sensors and animal tissue are exposed to identical thermal loads. An attempt was to be made to extrapolate the animal skin data to human skin. In addition, the effect of placing thermal protective fabrics between the physical sensors, or animal tissue, and the thermal source was to be studied to determine if a mathematical relationship could be derived which would allow physical sensor output to be interpreted in terms of the severity of tissue burn that would have occurred had animal or human tissue been used instead of a physical sensor.

Because of the size and scope of this project it was decided to present the final report as a series of volumes, each presenting a different project phase.

This volume contains a definition of the problem, a detailed discussion of the equipment and methodologies used to study the problem, and a general discussion of experiments performed. An annotated bibliography of reports and papers derivative from the Thermal Project is included as Appendix D of this report to assist the reader in pursuing topics introduced herein.

In a project of this scope, no one person or small group of people could have accomplished the task in the time allotted (two years). It is, therefore, appropriate and an honor to acknowledge the diligent efforts of all my colleagues. Those who participated in these studies are listed in the Preface as a way of acknowledging their contribution. Their efforts under sometimes trying conditions are deeply appreciated. For those members of the team who had a part in writing this report, I give a special vote of thanks and take pleasure in listing them as coauthors. The overall report organization and content is mine, and it, therefore, falls upon me to accept the criticism for all errors of omission and commission.

March 1979

FRANCIS S. KNOX III, Ph.D.
Associate Professor, LSU School of Medicine in Shreveport, LA 71130, and Consultant to USAARL, Fort Rucker, AL 36362

PREFACE

The vivarium of the United States Army Aeromedical Research Laboratory (USAARL) is fully accredited by the American Association for Accreditation of Laboratory Animal Care. The animals used in this study were procured, maintained, and used in accordance with the Animal Welfare Act of 1970 and AR 70-18. In conducting the research described in this report, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care," as promulgated by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences-National Research Council. Humane procedures were utilized throughout, and a graduate veterinarian was in constant attendance to perform all surgical procedures and to insure that all animals were fully anesthetized and insensitive to pain during any experimental procedure.

Many people contributed directly to the success of this project. The senior author expresses his thanks to the following people for their very great effort: Lynn A. Alford, John J. Barbaccia, David Bellemore, Charles E. Bishop, Don Blevins, Daniel Carpenter, Max B. Donaldson, David DuBois, Leon Dudewicz, Jr., W. Denny Freeston, Jr., Alford Jimmerson, Clifton P. Johnson, Nina P. Jones, George Keiser, Michael G. Medvesky, Diana Patrick, Darolyn A. Perez-Povedo, Scott Shortridge, George Volkov, C. D. Williams, and Linda Hoar.

Special thanks go to my coinvestigators, Doctors Wachtel, McCahan, Lum, Trevethan; Messrs. Sauermilch and Takata for their valuable assistance; and Doctors Bailey and Knapp for their encouragement and administrative support.

The work described in this report was accomplished by the staff of the USAARL and its subcontractors in a project funded jointly by the U. S. Air Force Contract FX 2826-70-05327 and the U. S. Army Medical Research and Development Command.

TABLE OF CONTENTS

CONTENTS (Cont.)

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

REVIEW OF THE PROBLEM

Military pilots, aircrew members, and passengers are subjected to the threat of fire during "hot" refueling, in flight accidents, and postcrash sequences. Many things may be done to protect people under such circumstances, but one of the more promising is the wearing of thermal protective clothing.

In order to minimize burns, the best fabrics and uniform designs must be chosen from among the many that are or will become available. The most direct way of evaluating proposed uniforms is to subject a man wearing a candidate uniform to a real postcrash fire. This happens all too frequently in the most expensive and crucial of all experiments, namely, an actual fire. Unfortunately, we do not have the scientific acumen to accurately assess, in retrospect, the many variables. Thus, we learn little.

A better approach is to subject an analog of human skin (pigskin) to a controlled, simulated postcrash fire. While this is the next best approach available, it suffers from the logistical drawbacks of time, manpower, cost, and scientific complexity.

The most reasonable approach for routine testing and evaluation of the thermal protective fabrics is to use well calibrated physical sensors to evaluate the heat transfer through and/or from the candidate fabrics when subjected to a well controlled simulated postcrash fire. The sensor's output should be interpretable in terms of burn damage that would have been suffered by a pig and, by inference, a man. Prior to this study, such interpretations were not possible.

The purpose of this study was to establish the correlation between parameters detected by physical (i.e., nonbiological) sensors and damage (burns) to animal tissue when both physical sensors and animal tissue are exposed to identical thermal loads.*

---

* Work Statement of Thermal Analysis Project, dated July 1971. US Air Force Contract FX 2826-70-05327.

In addition, the effects of interposing fabrics between the thermal source and physical sensors or animal tissue on this correlation were to be determined.

SCOPE FORMAT

This report describes the equipment and methods developed to conduct the experiments needed to elucidate the relationship between sensor output and animal tissue burns. The heat source, pig carrier/shutter mechanism, templates, data acquisition, animal handling, photographic, and histopathologic procedures are described. The experiments are outlined, but the results and data analysis are presented elsewhere (Takata, Rouse, Stanley 1973) (Knox 1979).

Finally, a discussion of the equipment and methodologies is presented.

HELICOPTER FIRE

Part of the work statement outlining the scope of this project called for two helicopters to be instrumented and burned. Only one such helicopter was available, and the test was conducted on 26 May 1972. The report of that test is the subject of USAARL Letter Report No. 73-6-3-2 by Calvin B. Lum, M.D.

METHODS AND MATERIALS

FURNACE DESIGN AND CALIBRATION

Furnace

After consideration of several possible flame sources, including a Federal Aviation Agency (FAA) flame gun (Knox and others 1971); an AVCO fire simulator (Belason and others 1970); meeker burner and quartz lamps,* it was decided to duplicate the National Aeronautics and Space Administration (NASA) AMES T-3 furnace.** According to the designer, Richard Fish, the AMES T-3 furnace was designed to simulate postcrash fires burning Jet Propelled-4 (JP-4).

The furnace is an insulating fire brick lined steel box heated by a commercial oil burner (Ray Burner Co., Type RCR, Size 00-1) burning JP-4. There are three one-foot square test areas in the furnace (Fig. 1, p. 32) which provide fairly uniform heat flux. Typical values for these areas are:

> Area 1, 2.4 - 4.3 calories per square centimeter per second; 90% radiative
>
> Area 2, 6.0 calories per square centimeter per second; mostly convective
>
> Area 3, 1.5 - 3 calories per square centimeter per second; 50% radiative

In our studies, test area 1 was utilized exclusively.

The USAARL T-1 furnace, Figures 2 and 3 (pp. 32 & 33), was constructed following blueprints and general specifications generously provided by Richard Fish, NASA Ames.**

Fuel System

The fuel system for the furnace consisted of a 5-gallon "jerry can" connected to a CONELEC electronic fuel pump (rated at 3 pounds per square inch for static flow) which provided a constant fuel pressure to the metering valve at the input to the oil burner. Fuel flow was monitored by a Gilmont F1300 Flowmeter. Flow rates (Fig. 4, p. 33) were calculated using a fuel density of 0.78 grams per milliliter and a viscosity of 1.0 centipoises for JP-4. The flow rates should be consiuered approximations because they do not take into account changes in atmospheric conditions.

---

* Stanton, R. Personal communication, 1971.

** Fish, R. Personal communication, 1971-1972.

Monitoring Instrumentation

Furnace output (heat flux) was monitored using a slug calorimeter and a Hycal asymototic calorimeter. The internal wall temperature was measured using a chromel/alumel thermocouple embedded in a steel plate mounted inside the furnace. The electrical signals from these sensors were conditioned and recorded on analog (FM) magnetic tape, strip chart recordings, and handwritten records of digital meter readings. The real time readout resulting in handwritten records was used to check the status of the furnace, prior to and during experimentation.

Furnace Performance

During these studies the performance of the USAARL T-1 furnace was evaluated in various ways. Table 1 (p. 38) summarizes this performance data.

As seen by the data in Table 1, the furnace was capable of reasonably simulating the thermal properties of large JP-4 fires (Albright and others 1971). The flame was observed to progressively fill the combustion chamber as fuel flows increased from 3.79 to 7.57 liters/hour. This was accompanied by an increase in the uniformity of the flame front at Test Area 1. Moreover, as the flame filled the combustion chamber, there was a decrease in the ratio of radiative to total heat flux; i.e., the convective component of heat transfer became larger. For example, at a fuel flow rate of 7.19 liters per hour, the ratio was .96, but the ratio dropped to .67 at a flow rate of 7.95 liters per hour.

Figure 4 (p. 33) shows the relationship between fuel flow and heat flux. The shift in the curves from 4 October to 12 October was probably due to changes in atmospheric conditions. For instance, it was observed qualitatively that changes in flow rate were required to maintain a given heat flux when the room air temperature and humidity changed. No attempt was made to condition or precisely control the air drawn into the combustion chamber.

Likewise, the velocity vector of the combusting gases in the furnace was not controlled. The flame front did not contact the test area from a normal direction. Instead, it swirled about sweeping across the port.

SHUTTER SYSTEM

Description

The exposure of the pigs and/or sensors to the fire was controlled by a water-cooled mechanical "focal plane" shutter. This steel shutter was mounted in a specially built pig carrier, shown in Figures 2 and 3 (pp. 32 & 33). During the course of the project, four mechanisms were used to propel the shutter. Each is described beginning in the section titled Single Bungy (see below). Displacement of the shutter as a function of time was recorded on video tape and played back one frame at a time. By recording the displacement per frame (one frame is 33.3 milliseconds), a graph depicting displacement as a function of time was developed for each method of propulsion. These are shown in Figures 5, 6, 7, and 8 (pp. 34 & 35). These graphs were used to determine the correction factors (Table 2, p. 39) which should be added to the recorded exposure time to give the actual exposure time for each burn site.

PERFORMANCE

Single Bungy

The first version of the shutter was propelled by a single loop of 3/8 inch rubber bungy or shock cord. It gave a fairly rapid opening response (210 milliseconds to open all template holes, Figures 5, 9, and 10, pp. 34 & 36), but a much slower closing sequence (606 milliseconds to close all holes). This large (88%) asymmetry causes holes 3 and 6 (Figs. 9 & 10, p. 36) to be exposed approximately 280 milliseconds longer than holes 1 and 4 (Figs. 9 & 10, p. 36). It was observed, also, that its performance from experiment to experiment was erratic.

Double Bungy

The first solution to the problems experienced with the single bungy method was to double the loops of 3/8 inch rubber shock cord. This resulted in nearly the same opening response time but a much reduced closing response time (from 606 to 340 milliseconds). The asymmetry was reduced from 188% to 65%. Holes 3 and 6 were exposed approximately 100 milliseconds longer than holes 1 and 4. The double bungy version operated in a much less erratic manner (Fig. 6, p. 34).

Fifty Pound Weight

In an attempt to further improve performance, a third method of powering the shutter was devised. The doubled bungy cords were replaced with a 50-pound weight which was accelerated by gravity. At the expense of a slightly slower opening sequence (288 vs. 206 milliseconds) the asymmetry was reduced to 5%. The displacement of the closing curve to the left (Fig. 7, p. 35) was caused by 1.5 inch extra travel experienced by shutter during opening. This method was cumbersome and added a significant overturning torque to the pig carrier.

Pneumatic

The final shutter propulsion system employed back-to-back nitrogen-powered pneumatic cylinders. This method had opening and closing times of 196 and 213 milliseconds respectively. Asymmetry between opening and closing increased slightly to 9%. Holes 1 and 4 were exposed approximately 38 milliseconds longer than holes 3 and 6. Mechanical considerations dictated that the direction of shutter motion be reversed so that holes 3 and 6 were opened first. This system had sufficient force to overcome all the friction imposed by the shutter on its rails. The result was a much more reliable performance (Fig. 8, p. 35).

TEMPLATE

During experimentation, the templates shown in Figures 9 and 10 (p. 36) were used. Both templates were of laminar construction using sheets of transite and leather.

During animal experimentation, the "animal" template (Fig. 9, p. 36) was used to circumscribe the burn sites. The holes in the leather and top transite sheet were identical. Holes in the bottom transite sheet are larger but concentric with the holes in the other two sheets. During experimentation using nonbiological sensors, the "sensor" template shown in

Figure 10 (p. 36) was used. Holes in the two transite sheets were concentric but had different diameters; the bottom transite sheet having the larger holes.

In the upper sheet of all templates, Holes 1 and 3 were 1-9/16 inches in diameter, while Holes 2, 4, and 6 were 2 inches in diameter. This difference permitted the effect of lateral heat conduction on burn grade to be studied.

As is discussed in Takata and others (1973), the template shaded the exposure site from some of the incident heat flux. To decrease the shading caused by a double layer template, the lower transite sheet had holes which were one-half inch larger in diameter than their mates in the upper sheet.

The templates are discussed in more detail in Appendix B.

DATA ACQUISITION SYSTEM

A data acquisition system (DAS) was developed to collect, process, and store information from the fire simulator, the pigs, the experimental sensors, and from the observations of the research staff. The resulting computerized data base provided easily accessible data upon which to build the Burn Prediction Model. Figure 11 (p. 37) shows the data flow through the acquisition system. A detailed description of the DAS is found in Appendix C.

There were three types of data generated in this experiment. Type I data are the data gained through animal experimentation. The experiments produced burns which were graded visually and pathologically. The values were recorded on handwritten records and later transcribed into computer records.

Type II data consist of miscellaneous observations made by the research staff. As with Type I data, these were first handwritten and later transcribed into computer records. Some examples of the types of observations which became Type II data are the following:

1. Date and time of experiment.
2. Amplifier gains.
3. Fuel flow.

4. Furnace temperature.
5. Smoke content of furnace exhaust.
6. Experiment configuration.
7. Initial skin temperature of animal.

Electrical signals from physical sensors comprise Type III data. These were recorded either as analog signals on an instrumentation tape recorder, or as printed output on a digital printer. The analog (FM) magnetic tape recording was later electrically converted to a digital computer tape recording. The digital printer output was manually reduced and hand recorded and later incorporated into computer records.

EXPERIMENTAL ANIMAL PROCEDURES

Procurement, Care, Housing

Ninety-five white, crossbred, mixed male and female, domestic swine were procured locally, quarantined for a minimum of 30 days, freed of internal and external parasites, and verified to be healthy prior to use in this study.

All pigs were ear-tagged upon initial entry and individual health records started and maintained. Temperatures were taken rectally twice a day using an electronic thermometer* and recorded on temperature charts. A Livestock Weather Safety Index (LWSI)** was calculated at least twice a day and whenever resuscitation procedures were used on a pig experiencing malignant hyperthermia.

Pens were located outside and consisted of 24 runs, 12 runs per side, with concrete floors and 4-inch high concrete dividers topped with free-standing chainlink fencing panels. All pens were 4 feet wide by 16 feet long with 4 foot wide gates opening onto a central aisle that was 8 feet wide. Runs were equipped with automatic waterers.*** A commercially

---

* GFA Electronic Thermometer Model #0071 and Model #0111, Agricultural Electronics, Montclair, CA 91763.

** Farm Journal, Hog Extra, 1972.

*** Lixit Dog Waterers, Atco Mfg. Co., Napa, CA 94558 prepared 16% protein pelleted feed was placed on the floor once or twice daily for the pigs, housed two per pen, to eat.

The entire area was covered. The interior half of each run and the center aisle were under a metal building with a high crown roof, and the outer half of the runs was covered by canvas. Eight large fans were used in conjunction with ordinary garden-type sprinkler hoses to help provide evaporative cooling and air circulation. Prior to experimentation and prior to biopsy, air only was used for cooling.

Each animal was handled extensively by the caretakers; as a result, a large number of manual manipulations could be done without animal excitement.

Site Preparation

Depilation of animals used in experimentation was accomplished by anesthetizing them and using a small animal clipper* with a #40 head. For the first 40 animals, this was done 3 to 5 days prior to experimentation, while the last 55 were clipped the day of use. Extreme care was used to insure that minor abrasions, nicks, and cuts, resulting from the clipping, did not occur. If found, such irritation was grounds for deleting that particular animal from use until complete recovery was noted (Wachtel, McCahan, Knox 1977). This rarely occurred.

Pigs were usually predosed with atropine (0.02 milligram/pound) administered intramuscularly approximately 20 minutes before gaseous anesthesia was given. The majority of the pigs were anesthetized using Halothane, USP, without complications; however, 12 cases of malignant hyperthermia were encountered. Through the judicious use of supportive therapeutics no animals that exhibited malignant hyperthermia were lost. A muscle relaxant drug was never employed.

Halothane was administered via nose cone until the pig's reactions were such that each could be intubated. Only three pigs could not be intubated safely, and in these, the nose cone was utilized throughout the entire procedure.

---

* Oster Model #A2, John Oster, Mfg. Co., Milwaukee, WI 53217.

Following induction of anesthesia, pigs were weighed on a 150 kilogram anthropometric scale* and then placed on the shutter/carrier for controlled movement over the heat source (Fig. 12, p. 37).

Burn Grading and Photo Documentation

Immediately after thermal exposure all pigs were photographed while still under the effects of anesthesia. A 35 mm camera** was used with a stand-off fixture to insure accurate placement of the camera.

Each burn site on the animal was photographed separately. Included in the photos were identification symbols and a color reference chart. Also, a photograph of each group of six burns was made. Immediately after the photographic documentation, the burns were visually graded by two members of the staff (a burn surgeon and a veterinarian).

At 24 hours postburn, each site was rephotographed and regraded by the same two staff members and the results recorded. At this time the pig was restrained, unanesthetized, on the photography table by handlers.

Immediately following this the pig was given an injection to render it unconscious, and it was exsanguinated. At this time a medical illustrator sketched the configuration of the burn depicting the location of the individual incisional biopsies.

The gross (clinical) evaluation included surface appearance, hair removal, sensation, and tactile response. Of these methods surface appearance was the most important. Details of the clinical grading system may be found in Wachtel, Knox, and McCahan (1978).

---

* Fairbanks Model 41-3314, Fairbanks-Morse Weighing System Div.

** Nikon F. Body, Medical-Niccor 55 mm f 3.5 lens; Kodak CX-135 ASA 80 color negative film, with strobonar flash unit (3400° K).

Biopsy Procedures

Biopsy tissues were taken to encompass the area as it had been graded grossly (i.e., the area that was most typical of the burn and that had received the numerical rating picked as representative of the burn) and extended into normal tissue surrounding the burn. The same investigator did all the biopsy taking, and a different individual was personally responsible for insuring that each specimen was placed in the appropriately prelabeled specimen container. Plastic bags,* containing a solution of unbuffered 10% formalin, were prepositioned in a compartmentized holder and carefully handled to insure that each sample went into the correct bag. The bags were then heat sealed,** stored overnight to check for leaks, and packaged for delivery to the veterinary pathologist for microscopic examination.

Necropsy

A modified necropsy, to verify the health of the experimental subjects, was completed on each pig used in this study. All were found to be without significant pathological manifestations. A single pig was noted to have small numbers of lungworms in one lobe.

HISTOPATHOLOGY

The formalin fixed skin specimens were assigned a pathology accession number upon receipt at the Naval Aerospace Medical Research Laboratory. The specimens were dehydrated, embedded, sectioned at 6-7 microns, and stained with Hematoxylin and Eosin. The stained slides were read by a veterinary pathologist for degree of burn depth. Detailed procedures for specimen preparation and grading may be found in USAARL Report No. 78-11, by Knox and others (1978).

---

* Bag, Plastic, Pathological Specimen, FSN 8105-299-9802.

** Scotchpak Package Sealer, Kapak Industries, Bloomington, NM 55431.

EXPERIMENTS

It was necessary to perform a number of different experiments to gain the data required to build the Burn Prediction Model. Even though each experiment was quite different, they all may be categorized as either biological or physical experiments.

Biological Experiments

There are four types of experiments which we categorized as biological experiments. The order in which experiments are discussed does not imply the order of their execution.

The first experiment was to determine the amount of water in skin available to support steam blister formation. The procedure used was to take numerous samples of porcine skin and measure their volume, thickness, and weight. Then dehydrate the samples and weigh them again. The difference in weight was due to water evaporation. The dehydration procedure was as follows:

1. Weigh samples.
2. Heat samples to 110 degrees centigrade for 3 days.
3. Cool samples in desiccation chamber.
4. Reweigh samples.
5. Repeat process until no weight difference is detected.

The result of the experiment was a profile of water concentration versus depth beneath the surface. This profile is shown in Table 5 (p. 41), Takata, Rouse, and Stanley (1973) and is discussed in more detail in Knox (1979).

The second experiment had two objectives: (1) determine the time required to initiate blister formation during the burning process, and (2) verify the absorptivity of natural porcine skin. The materials used were an anesthetized white pig, one high intensity quartz-iodide lamp,* a sheet

---

* Torchlamp, Model TL-2, Smith-Victor Corp., Griffith, ID 46319.

of soft asbestos with a 3-inch hole cut in its center, a television camera and recorder,* and black spray paint.**

The method was straightforward. The anesthetized pig was placed on its side on a table. The asbestos sheet was placed atop the animal so that the hole exposed the skin directly beneath it. Then the lamp, at a distance of from 2 to 10 inches, was turned on. Once a blister formed, the lamp was extinguished and the asbestos sheet removed.

During the exposure process, the television recorder photographed the activity of the blistering animal skin. When the video recording was replayed, the single frame feature of the recorder was used. This allowed the experiment to be viewed as a series of still photographs separated in time by 33.34 milliseconds. Thus, it was possible to measure the time between the start of exposure and the start of blister formation. By exposing both natural skin and skin blackened with paint of known absorptivity, the absorptivity of the natural porcine skin could be calculated (Takata, Rouse, Stanley 1973).

The third experiment also had two objectives: (1) assess the effects of immediate cooling on potential burns, and (2) gain additional data for the construction of the Burn Prediction Model.

The materials were an anesthetized pig; two aluminum disks, 43.2 mm in diameter and 5 mm thick; a container of boiling water; a container of ice water; and a watch.

Again, the method used was simple. The pig was placed on its side atop a table. One aluminum disk was at thermal equilibrium in the boiling water and the other disk was in equilibrium in the ice water. First, the hot disk was removed from its bath and quickly pressed against a portion of the animal's skin. After 10 seconds, it was quickly removed, and the cold disk was taken from its bath and placed on the previously heated skin. The "cold" disk remained in place until it came to the thermal equilibrium with the pig (See Takata, Rouse, Stanley 1973 for detailed discussion).

---

* Sony-Matic Portable Videocorder, Sony Electronics Corp., Japan.
** Nextel Brand Velvet Coating, 101-C10 Black, 3M Company, 3M Center, St. Paul, MN 55101.

The fourth biological experiment involved exposing porcine skin to various severe heat loads. The objective was to collect enough data to build and adjust the USAARL/IITRI Burn Prediction Model. The materials used were the USAARL T-1 furnace, the pig carrier/shutter mechanism, animal and sensor templates, anesthetized pigs, and miscellaneous instrumentation.

In this experiment, many animals were processed in nearly identical fashion. Therefore, explaining the experimental procedure for one animal will render all the essential details. The experimental procedure was as follows:

1. Render animal unconscious with gaseous anesthesia prior to experiment.
2. Remove hair from candidate exposure sites.
3. Place animal on pig carrier/shutter and transport to and onto the T-1 furnace.
4. Deliver measured heat load to exposure sites.
5. Repeat Step #4 one to three times depending upon protocol of particular experiment. Different sites on the animal were used for each exposure.
6. Transport animal to photography table; grade and photograph burns.
7. Measure output flux of furnace with calorimeters.
8. Return animal to its run.
9. At 24 hours postburn, grade and photograph burns.
10. Take histopathological tissue samples.

The results of these experiments thus obtained were placed on computer records and used to test the Burn Prediction Model (Takata, Rouse, Stanley 1973) (Knox 1979).

Physical Experiments

Aside from the experiments designed to study thermal burns directly, there were five other experiments which, by convention, we have termed physical experiments. Again, the order in which they are discussed is not necessarily the order in which they were performed.

The objective of the first physical experiment was to determine the fraction of incident heat flux in the biological exposure experiments that was intercepted by hair stubble. This required two tasks. First, the length, diameter, and number of the hairs per unit area were measured. Then, a mathematical function to account for the intercepted flux in terms of measured quantities was derived. See Takata, Rouse, and Stanley (1973) for details.

The second experiment was conducted to evaluate the uniformity of the heat flux, both total and radiative, appearing at each of the animal template holes. The equipment used was a Hy Cal calorimeter, a Hy Cal Radiometer, a differential amplifier, (NLS) Model XL2 digital voltmeter, a Model 800 Newport digital printer, the USAARL T-1 furnace, an animal template, and the pig carrier/shutter assembly.

The procedure was as follows:

1. Allow the T-1 furnace to stabilize at the desired flux output.
2. Place an animal template on the pig carrier/shutter assembly and position both over the T-1 furnace.
3. Activate the digital printer which records the scaled output of the Hy Cal calorimeter.
4. Activate the shutter allowing the furnace heat flux to appear at the template holes.
5. Insert the calorimeter into each of the template holes for 15 seconds.
6. Repeat steps 3, 4, and 5 using the Hy Cal Radiometer connected in place of the calorimeter.
7. Change the T-1 furnace adjustments to produce a new desired output.
8. Repeat steps 1 through 7.

The result of this experiment was a total and a radiative heat flux distribution for each of the animal template holes for different furnace settings shown in Table 1 (p. 38).

The objective of the third physical experiment was to correlate the responses of a Hy Cal calorimeter with those of the IITRI slug calorimeter. The equipment used was a Hy Cal calorimeter, the IITRI slug calorimeter, the electronic instrumentation associated with each sensor, the sensor template, the pig carrier/shutter mechanism, and the USAARL T-1 furnace. The experimental procedure was as follows:

1. Allow the T-1 furnace to stabilize at the desired output.
2. Place one of the calorimeters in hole #5 and the other in hole #2 of the sensor template, Figure 10 (p. 36); place the template on the pig carrier/shutter; and place both atop the furnace. Connect the calorimeter to its instrumentation.
3. Actuate the shutter, thereby exposing the calorimeter to the furnace output.
4. Record the calorimeter response.
5. Switch calorimeters.
6. Repeat steps 3, 4, and 5 several times.

At the conclusion of this experiment, a relationship between the responses of the two calorimeters was determined. It is presented in Section 3.9 of Takata, Rouse, and Stanley (1973).

Fabric Research Lab (FRL) and Aerotherm sensors are used to assess heat transfer through fabrics. Since the accuracy of either the FRL or Aerotherm sensor is determined by the placement of its internal thermocouple, establishing the reproducibility from sensor to sensor was the objective of the fourth physical experiment.

The materials included several FRL and Aerotherm sensors, the sensor template, the USAARL T-1 furnace, and miscellaneous instrumentation. The USAARL T-1 furnace was modified by placing a sheet of 12.7 mm steel boiler plate in Test Area 1, Figure 1 (p. 32). Thus, the furnace had a 1-foot square port which had an extremely uniform temperature distribution. The pig carrier/shutter mechanism with the sensor template was placed over the furnace. Several sensors of both types were placed in the template holes and exposed repeatedly to the radiation from the hot boiler plate. By this method, the reproducibility of these sensors was established. The analysis of the experimental results can be found in Sections 5.2, 5.3, and 5.4 of Takata, Rouse, and Stanley (1973).

As previously mentioned in the section on the Shutter System, the pig carrier/shutter mechanism had four different systems which propelled the shutter. Since each system was quite different in performance, an experiment was undertaken to document the shutter's responses. The equipment for this experiment included a television camera and recorder,* the pig carrier/shutter mechanism with each of its actuation systems, and the associated control equipment.

The procedure for evaluating shutter performance was simple. Each time the propulsion system of the shutter changed, its performance was documented. This was done by putting timing marks on the shutter and recording its opening and closing cycles with the television equipment. Using the single frame replay feature of the recorder, the USAARL staff viewed the shutter movements as a series of still "photographs" separated in time by 33.34 milliseconds. From these data, the displacement graphs shown in Figures 5, 6, 7, and 8 (pp. 34 & 35) and the exposure corrections, Table 1 (p. 39), were generated.

DATA SAMPLE

As mentioned in various other parts of this report, all the experimental data were eventually stored as digital records on magnetic tape and on disk. Such storage facilitates retrieval and manipulation for model building. An example of one such retrieval and listing is the set of data tables, TABLES J-1 through J-68, found in Appendix J of Takata, Rouse, and Stanley (1973). Table 5 (p. 41) is presented here as typical of Tables J-1 through J-68. In this table, the first four entries were data recorded at the time of experimentation, while the latter five items were recorded after laboratory evaluation of samples was complete. Obviously, more information than that which is displayed here was stored. Also, many other possibilities of organization and display exist. This listing is not viewed as the final base.

DISCUSSION

In this section, each major area of the project will be discussed in order to bring together the accomplishments and problems encountered. Since Takata, Rouse, and Stanley (1973) and Knox (1979) are devoted to data analysis and model development, the present discussion centers not on experimental results but on experimental methods.

---

* Sony-Matic Portable Videocorder, Sony Electronics Corp., Japan.

FURNACE

As a fire source we chose to duplicate the NASA Ames T-3 furnace. This furnace provides high thermal radiation levels characteristic of large postcrash fires coupled with some degree of convective heating.

The latter is associated with the combustion of JP-4 and resultant movement of hot gases into contact with the test specimen. The flame front is relatively uniform being no worse than ±11% at low heat flux levels and ±3% at high heat flux levels. It is apparent after discussions with the original designer, Richard Fish, that better control of the furnace could be effected by controlling the air input. As used in these studies, however, the furnace heat flux output had to be measured during each test in order to insure that thermal input to the test subject (pig or sensor) was known.

SHUTTER

The duration of thermal exposures was controlled by a water cooled shutter. The shutter propulsion system went through three variations before the fourth and final design was built. Each version was an improvement on the preceding systems. The final version could be improved still further by lightening the shutter and eliminating much of the sliding friction. Much of the opening and closing asymmetry could be eliminated by doing away with the 3.8 cm overlap which allows the shutter to reach higher velocity when it opens the holes than when it closes the holes.

The lift mechanism on the pig carrier could be improved to facilitate positioning the carrier over the furnace; likewise, tracks would facilitate rolling the carrier into position. These changes would not effect the data but might reduce some manpower requirements.

TEMPLATES

Templates were used to circumscribe burn sites on the pigs and to hold the sensors. The only major problems with the templates involved the need to make them thinner in order to reduce the shading and more durable in order to reduce thermal and mechanical breakage. The need for two sheets of transite could be eliminated by using a different material with better mechanical and thermal characteristics. The leather insulation could be eliminated if the template had better insulating properties. The templates could be water or air cooled, but should not be cooled to the point where they pull heat away from the tissue surrounding a burn site. The templates were adequate but should be redesigned in future studies.

DATA ACQUISITION SYSTEM (DAS)

The DAS was designed to preserve as much information as possible in a form suitable to compute analysis. Unfortunately, the slow sampling rate of the Digital Voltmeter/Printer used to generate the numbers which formed the hand-recorded heat flux records raises the question of accuracy. Since the heat flux fluctuated ±5 - 10% as seen from strip chart records, the hand-recorded heat flux data are no better than ±10%. The analog records which were digitized at 100 samples per second and stored on digital magnetic tape will allow for better data reduction including analyses of sensor dynamics and furnace fluctuations. These records will be analyzed and reported in a future report.

ANIMAL PROCEDURES

The animal procedures are adequately refined. Early in the project 12 animals gave evidence of having malignant hyperthermia (MH). Procedures were developed for managing animals with MH; these procedures will be discussed in a separate report.

With corrections for interception of radiation by pig hair of known length, diameter, and density, it was possible to clip the pigs just prior to thermal exposure. Clipping leaves more stubble than depilation or shaving, but was found to be the best overall technique for hair removal (Wachtel, McCahan, Knox 1977).

Documentation photography is a valuable adjunct to the gross burn grade as a means of preserving evidence of burn severity. Photographic techniques including standardization of lighting, format, and focus were improved over previous studies. Future studies, however, will require further refinement in order to produce consistently acceptable results. All photos are maintained on file so that gross burn grades which appear out of line can be checked.

HISTOPATHOLOGY

Here again the procedures are well defined and produce consistent results. The few inconsistencies that exist derive from the difficulty in cutting good sections from the more severely damaged tissue, variations of burn severity within the tissue specimen, and thermal shrinkage caused by burning. The problem of thermal shrinkage may be a major cause for the scatter of the data and could be corrected for by making an additional depth measurement. The slides made from tissue samples will be reread to determine the extent of shrinkage and the influence of shrinkage on the burn depth. The results are reported in Knox (1979) and Knox and Nockton (1977).

EXPERIMENTS

There were many different experiments conducted during this project (See Experiment, p. 18). The results of many of these studies are analyzed and discussed in Takata, Rouse, and Stanley (1973) and in Knox (1979).

DATA

Some of the data are presented in Appendix J of Takata, Rouse, and Stanley (1973). These data contain bias and error such as the effect of thermal shrinkage on burn depth and inaccuracies in heat flux measurements due to slow sampling rate. For this reason the reader is cautioned against using the data directly for modeling. It is expected that when the biases are quantified, it will be possible to generate tables of corrected data which will more accurately reflect what really occurred. These data will be published in a future report.

SUMMARY

A thermal source, USAARL T-1 furnace, was built and calibrated. This source reasonably duplicates the thermal properties of a postcrash JP-4 fire. It was used to subject pigs and physical sensors to simulated postcrash fire conditions. The resultant burns were graded on both gross (clinical) and microscopic levels. The sensor outputs were recorded on both handwritten records and on analog (FM) magnetic tape for subsequent correction of temperatures or heat fluxes as appropriate. The sensors included a slug calorimeter, a Hy Cal calorimeter, FRL skin simulants and Aerotherm heat flux sensors. Both pigs and sensors were tested under a variety of conditions including natural and blackened surfaces, protected and unprotected by fabrics, and various combinations of heat flux and exposure times.

The basic equipment and methodologies were presented in this volume while preliminary results and analyses are presented in Takata, Rouse, and Stanley (1973).

A simulated postcrash, JP-4, fire involving an instrumented UH-1 hulk was conducted and documented in USAARL Letter Report No. 73-6-3-2.

CONCLUSIONS

The equipment and experimental procedures developed during this study have been successfully utilized to gather data which will allow conversion of the output from nonbiological heat flux sensors into predictions of the depth of irreversible damage to skin that would have occurred under similar thermal exposure.

REFERENCES CITED

Albright, D., Knox, F. S. III, DuBois, D. R., and Keiser, G. M. 1971. *The testing of thermal protective clothing in a reproducible fuel fire environment, a feasibility study.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 71-24.

Belason, B. [and others]. 1970. A fire simulation facility for materials response testing. *Fire Technology.* 6(3): 179-188.

Knox, F. S. 1979. *Predictability of burn depth: data analysis and mathematical modeling based on USAARL's experimental porcine skin burn data, final report.* Ft. Detrick, Frederick, MD: U. S. Army Medical Research and Development Command. Contract No. DAMD17-77-C-7004.

Knox, F. S. [and others]. 1971. *Engineering test of lightweight underwear of the winter flight clothing system: thermal protection.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 71-19.

Knox, F. S. III, and Nockton, R. A. 1977. *Predictability of burn depth: data analysis and mathematical modeling based on Army Aeromedical Research Laboratory experimental porcine burn data.* Ft. Detrick, Frederick, MD: U. S. Army Medical Research and Development Command. Contract No. DAMD17-77-C-7004.

Knox, F. S. III, Wachtel, T. L., Trevethan, W. P., McCahan, G. R., Jr., and Brown, R. J. 1978. *A porcine bioassay method for analysis of thermally protective fabrics: a histopathological and burn depth grading system.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 78-11.

Lum, Calvin. 1973. *Instrumented helicopter burn.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL-LR-73-6-3-2.

Takata, A. N., Rouse, J., and Stanley T. 1973. *Thermal analysis program.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. Contract No. DA13C01-G-0309. Report No. IITRI-J6286.

Wachtel, T. L., Knox, F. S. III, and McCahan, G. R., Jr. 1978. *A porcine bioassay method for analysis of thermally protective fabrics: a clinical grading system*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 78-8.

Wachtel, T. L., McCahan, G. R., and Knox, F. S. III. 1977. Methods of preparing porcine skin for bioassay of thermal injury. *Military Medicine*. 141(7): 536-538.

APPENDIX A

FIGURES AND TABLES

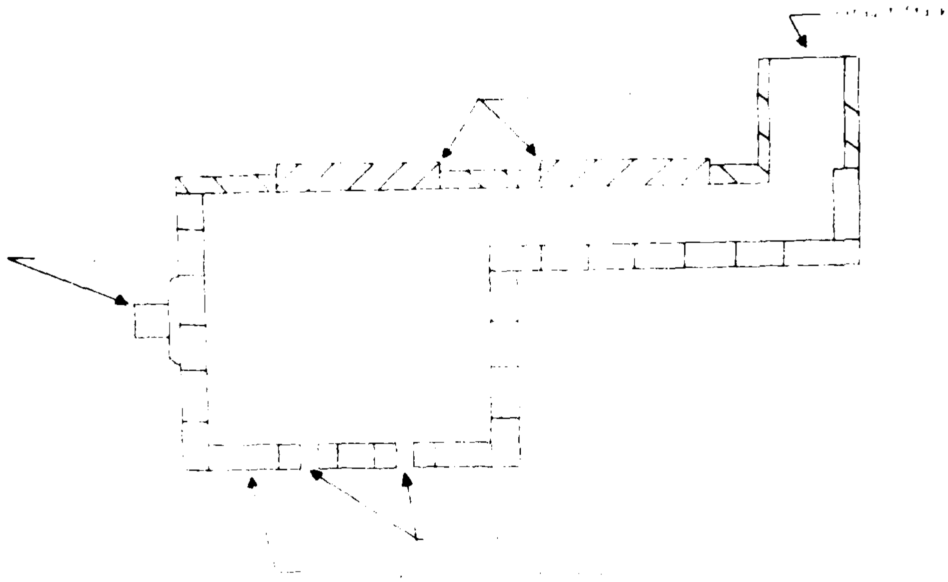


FIGURE 1. Cross Section Drawing of USAARL T-1 Furnace.

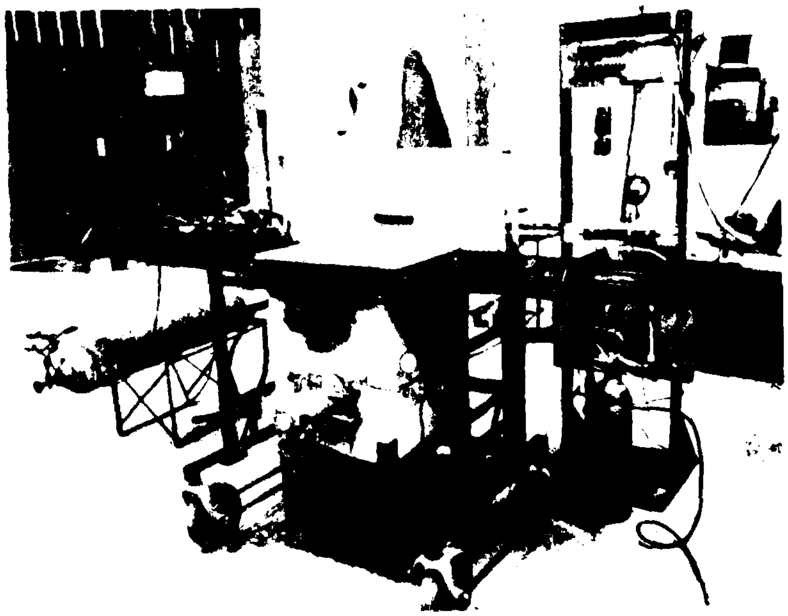


FIGURE 2. USAARL T-1 Furnace Facility and Pig Carrier/Shutter System.

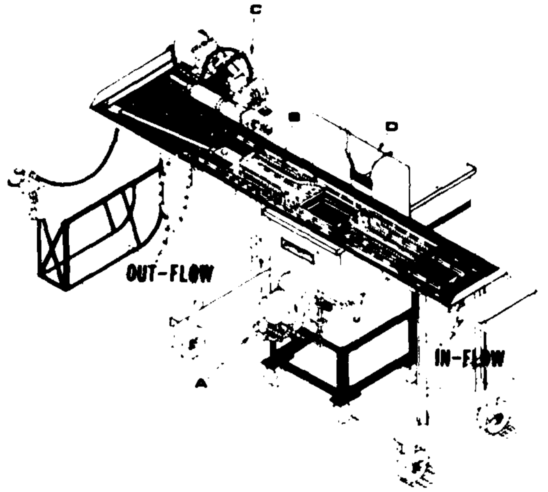


FIGURE 3. Cutaway Drawing of USAARL T-1 Furnace/Shutter System Showing: A) Oil Burner; B) Water-Cooled Shutter; C) Pneumatic Shutter Propulsion Mechanics; and D) Connectors for Instrumentation.

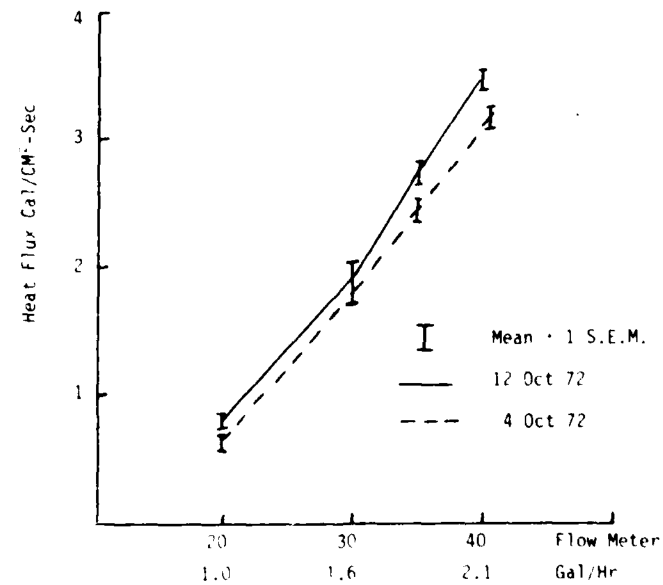


FIGURE 4. Relationship of Total Heat Flux Versus Fuel Flow For USAARL T-1 Furnace.

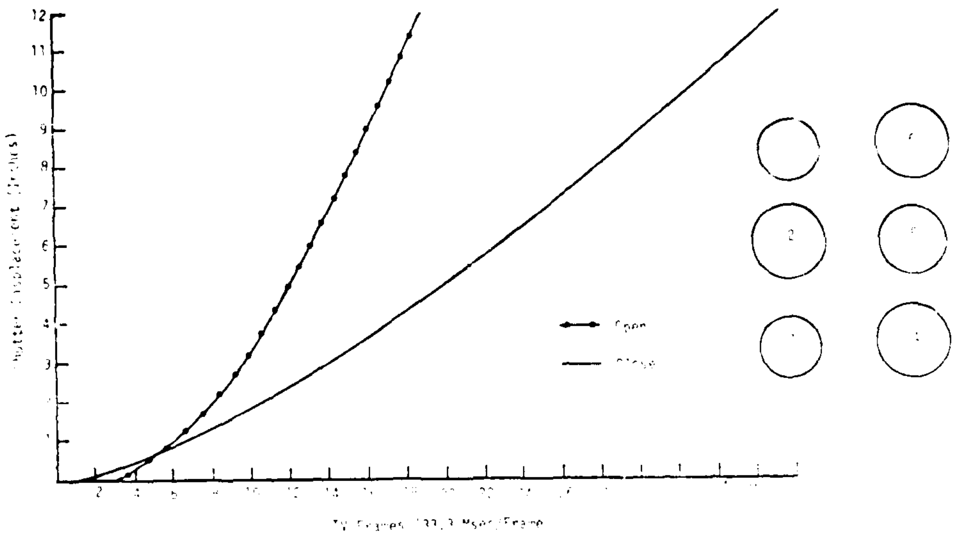


FIGURE 5. Shutter Displacement vs. Time Using Single Bungy Propulsion System.

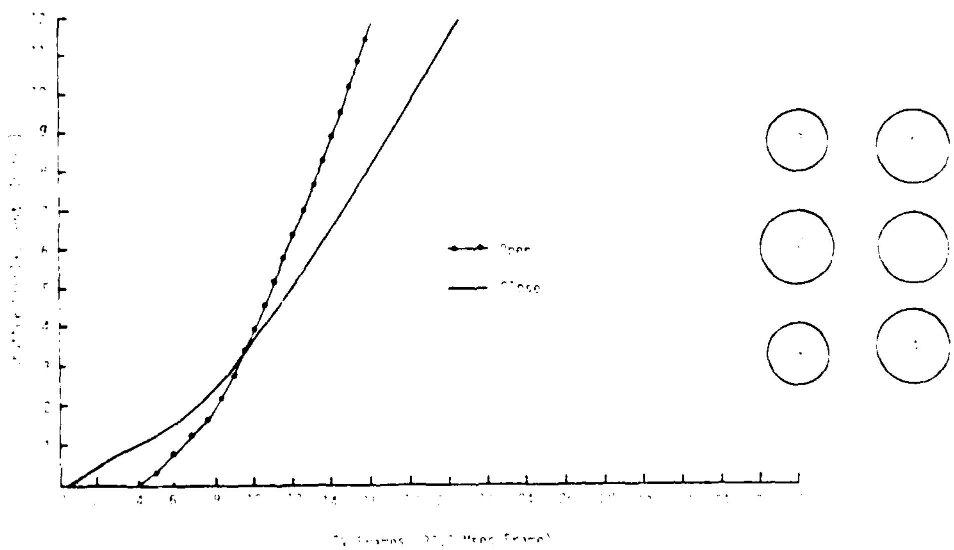


FIGURE 6. Shutter Displacement vs. Time Using Double Bungy Propulsion System.

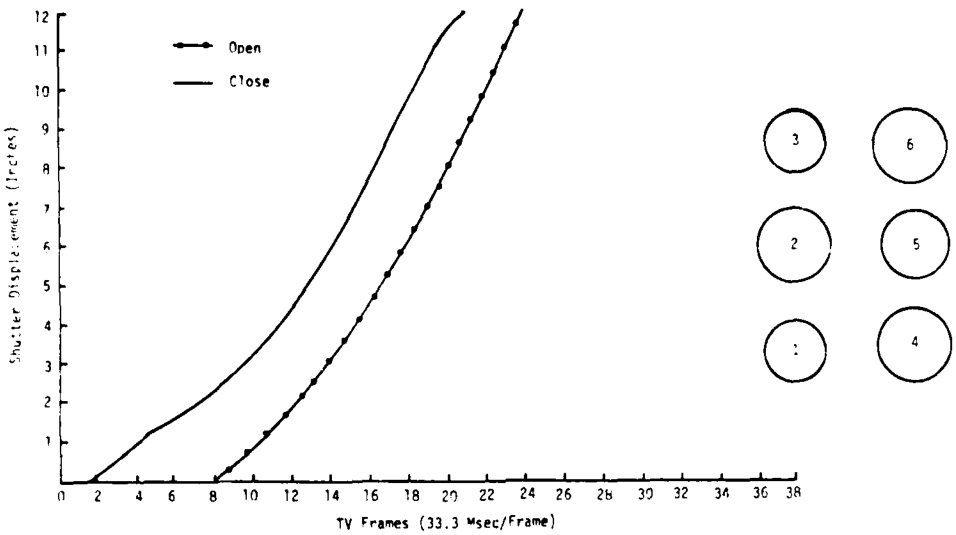


FIGURE 7. Shutter Displacement vs. Time Using 50-Pound Weight Propulsion System.

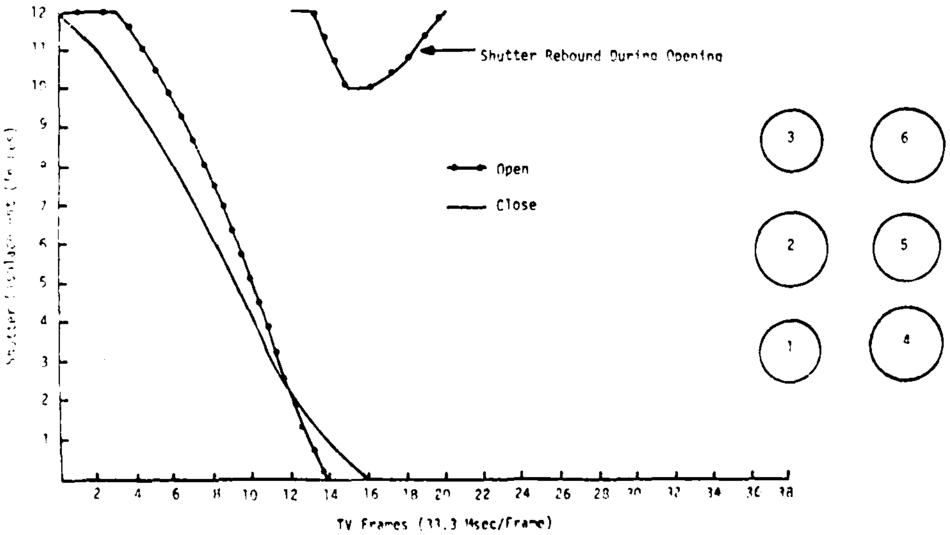


FIGURE 8. Shutter Displacement vs. Time Using Pneumatic Propulsion System.

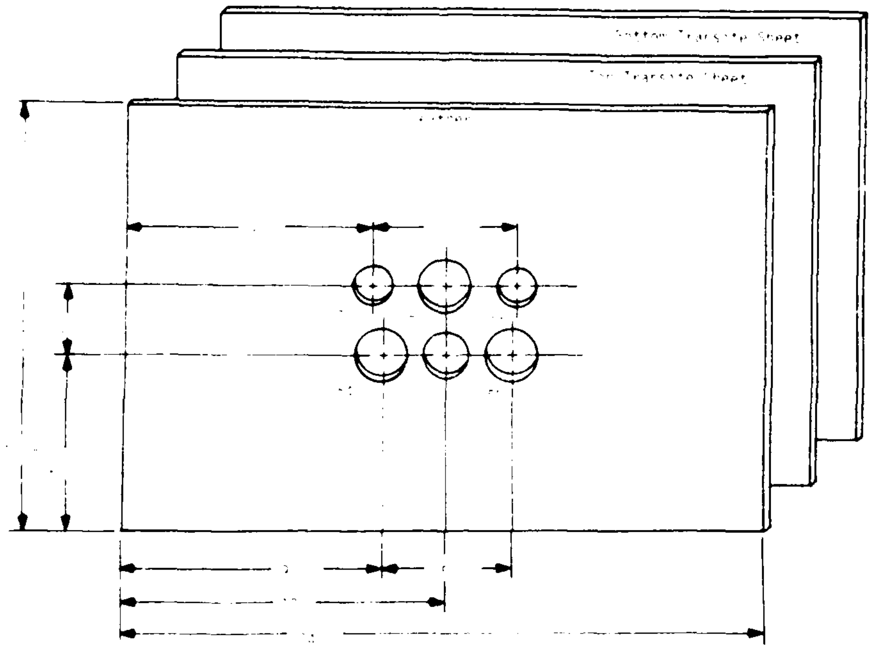


FIGURE 9. Animal Template

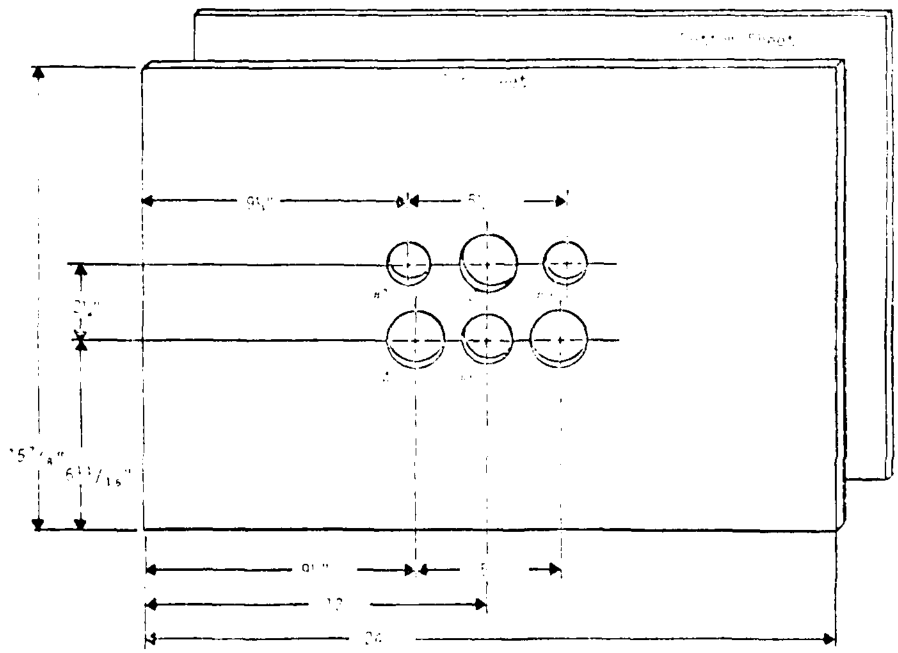


FIGURE 10. Sensor Template

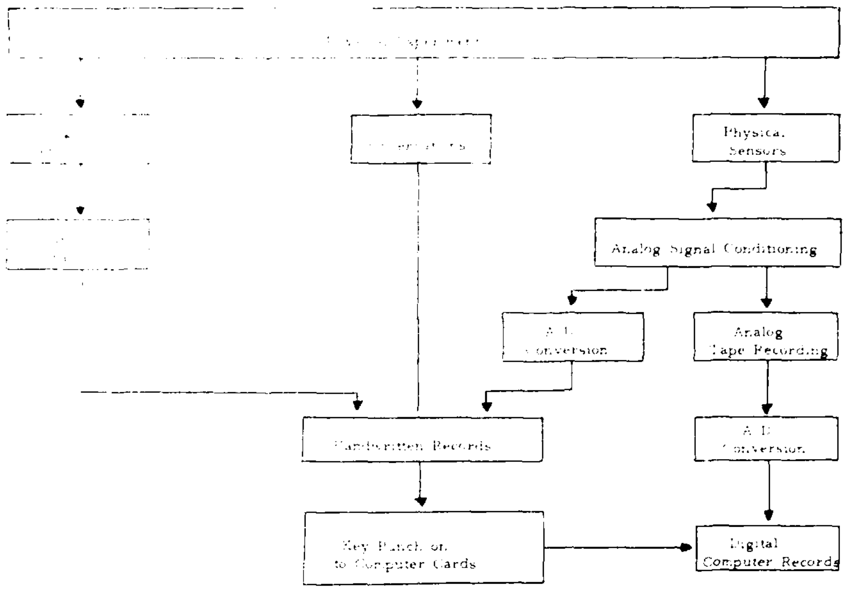


FIGURE 11. Data Flow

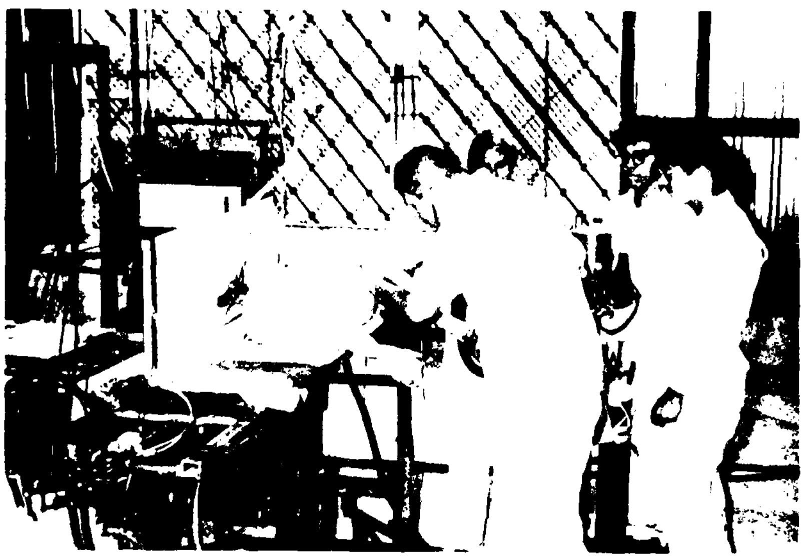


FIGURE 12. Anesthetized Pig on Shutter/Carrier Being Monitored by G. R. McCahan, D.V.M., Just Prior to Exposure to Simulated Postcrash Fire. (Originally Used In: Knox, F. S. III, McCahan, G. R., Jr., and Wachtel, T. L. 1974. *Aerospace Medicine*. 45(8): 933-938.)

TABLE 1

PERFORMANCE OF USAARL T-1 FURNACE

Fuel: JP-4

Total Heat Flux, Q (Area 1) 0.5 to 3.6 cal/cm²/Sec ± 3%

Wall Temperature: 967-2457°F ± 1.0%

Heat Flux as a function of time ± 5-10% at 1-2 Hz

Warm-up Time: 30 min.

Air-Fuel Ratio: Set "Rich" to produce a smokey fire. Air flow, air temperature, and humidity were not monitored.*

MODE OF HEAT TRANSFER

Fuel Flow	Total Q†	Radiant Q†	% Radiation
3.79 l/hr	0.57 ± 0.04	0.54 ± 0.02	95.5 ± 9.4
7.19 l/hr	2.32 ± 0.11	2.23 ± 0.06	96.5 ± 3.8
7.95 l/hr	3.07 ± 0.07	2.07 ± 0.12	67.2 ± 3.6

UNIFORMITY OF FLAME FRONT

Fuel Flow	Total Flux†
3.79 l/hr	0.74 ± 0.08 (± 10.8%)
6.06 l/hr	1.89 ± 0.19 (± 10.0%)
7.19 l/hr	2.75 ± 0.16 (± 5.8%)
7.95 l/hr	3.48 ± 0.08 (± 2.3%)

* Air temperature and humidity recorded twice daily.

† Average for all six template holes. Mean ± 1 S.D. (± %)

LEGENDS:
- cal — calories
- °F — degrees Fahrenheit
- hr — hour
- min — minutes
- sec — second
- cm² — centimeters squared
- l — liter
- Hz — Hertz
- S.D. — Standard Deviation

TABLE 2

CORRECTION TO EXPOSURE TIME BY TEMPLATE HOLE
AND SHUTTER DRIVE MECHANISM
(Time is in milliseconds. The "Leading" side is
opened or closed first.)

Hole	Side	Single Bungy	Double Bungy	50 Lb. Weight	Pneumatic
1	Leading	113	(-) 23	(-)143	(-) 3
	Center	173	0	(-)133	(-)13
	Trailing	227	23	(-)130	(-)22
2	Leading	278	42	(-)132	(-)30
	Center	333	63	(-)128	(-)33
	Trailing	385	80	(-)128	(-)41
3	Leading	426	93	(-)128	(-)48
	Center	466	103	(-)127	(-)52
	Trailing	506	113	(-)127	(-)57
4	Leading	113	(-) 23	(-)143	(-) 3
	Center	186	7	(-)127	(-)15
	Trailing	246	32	(-)132	(-)27
5	Leading	283	43	(-)133	(-)30
	Center	333	63	(-)128	(-)33
	Trailing	380	77	(-)128	(-)40
6	Leading	408	87	(-)129	(-)44
	Center	456	102	(-)127	(-)52
	Trailing	506	113	(-)127	(-)57
Time to Open All 6 Holes		210	206	286	196
Time to Close All 6 Holes		606	340	301	213
Asymmetry Error		188%	65%	5%	9%

TABLE 3

TEMPLATE HOLE SIZE FOR ANIMAL TEMPLATE
(Shown in Figure 9, p. 36)

	Diameter of Holes in Inches		
Hole No.	Leather Sheet	Top Transite Sheet	Bottom Transite Sheet
1	1 9/16	1 9/16	2 1/16
2	2	2	2 1/2
3	1 9/16	1 9/16	2 1/16
4	2	2	2 1/2
5	1 13/16	1 13/16	2 5/16
6	2	2	1 1/2

TABLE 4

TEMPLATE HOLE SIZE FOR SENSOR TEMPLATE
(Shown in Figure 10, p. 36)

	Diameter of Holes In Inches	
Hole No.	Top Transite Sheet	Bottom Transite Sheet
1	1 9/16	2 1/16
2	2	2 1/2
3	1 9/16	2 1/16
4	2	2 1/2
5	1 13/16	2 5/16
6	2	2 1/2

TABLE 5

SAMPLE OF DATA DISPLAY FOUND IN TAKATA, ROUSE, & STANLEY (1973)
(Skin Burn Data With Fabric = NF, and Skin Condition = 0; Exposure Time Between 3.0 and 5.0 Sec., Increasing Flux)

Pig	Exposure Time Sec	Exposure Flux Cal/Cm^2 Sec	Initial Skin Temperature Deg. C	Wall Temperature Deg. C	Gross Exam	Micro Exam	Depth of Dermis Burnt Cm	Epidermis Thickness Cm	Dermis Thickness Cm
247RF-2	4.09	2.20	35.8	953.	12	7	.092	.008	.211
247RF-4					12	8	.102	.006	.201
247RF-6					12	7	.112	.000	.223
251RF-2	4.13	2.24	36.9	825.	11	9	.144	.006	.248
251RF-6					11	8	.112	.007	.206
251RR-2	4.13	2.24	36.9	843.	11	7	.084	.008	.231
251LF-2	4.00	2.24	36.2	813.	10	7	.112	.007	.260
251LF-4					11	9	.112	.007	.223
251LF-5					11	6	.045	.007	.226
247LR-2	4.00	2.34	35.2	954.	12	7	.104	.007	.186
247LR-4					12	8	.097	.008	.223
247LR-6					11	8	.099	.007	.000
245LF-2	4.13	2.34	35.3	866.	10	8	.133	.009	.260
245LF-4					12	7	.104	.007	.223
245LF-6					10	8	.112	.005	.216
247RR-2	4.09	2.38	35.8	969.	13	8	.094	.008	.188
247RR-4				969.	13	7	.064	.008	.198
247RR-6					13	7	.092	.007	.280
246RR-2	4.08	2.38	35.4	949	12	7	.099	.006	.246
246RR 4					12	7	.087	.009	.223
246RR-6					14	7	.136	.008	.265
247LF-2	4.09	2.43	35.6	968.	13	7	.112	.011	.243
247LF-4					13	8	.117	.006	.186
247LF-6					11	8	.131	.007	.211

APPENDIX B

TEMPLATE

INTRODUCTION

Much of the experimentation in this project required the use of the USAARL T-1 furnace and pig carrier shown in Figures 2 and 3 (pp. 32 & 33). In addition, during the fire exposures, it was necessary to use the transite templates shown in Figures 9 and 10 (p. 36) to provide animals with thermal insulation and mechanical support. As suggested by Figures 9 and 10, there were two different sets of templates, one set used during animal experimentation, and the other set used only with heat flux sensors. Each set had six holes, but with different centers and diameters as is shown by Figures 9 and 10. In all experiments, a slug calorimeter was situated in hole #5 of the template to monitor furnace output.

ANIMAL EXPERIMENTS

Whenever experiments were performed with animals, the template shown in Figure 9 (p. 36) was used. The transite sheets provided all the mechanical support and most of the thermal insulation afforded the pig. The leather sheet furnished padding and additional insulation. Hole #5 of the template was used to hold the slug calorimeter described in Takata, Rouse, and Stanley (1973), Section 3.9.1. A detailed cross-section appears in Figure B-1A (p. 45). Table B-1 (p. 44) gives pertinent data concerning Figures B-1A and B-1B (p. 45).

There were two basic experimental arrangements. In one, the pig was exposed directly to the furnace heat. A detailed drawing of the cross-section of the burn site is found in Figure B-1B (p. 45). In this type experiment, template hole numbers 1, 2, 3, 4, and 6 resulted in burns, while hole number 5 housed the slug calorimeter. In the second type experiment, one or more layers of fabric were placed between the pig and fire.

There were several different arrangements of fabrics. These are illustrated in cross-section in Figure B-2 (p. 47), while Table B-2 (p. 46) gives relevant information. In such experiments, there was always one template hole which remained unobstructed to serve as a control. In all experiments, hole #5 always held the slug calorimeter.

SENSOR EXPERIMENTS

In addition to live porcine skin, heat flux sensors were also exposed to the flames of the USAARL T-1 furnace. When this was done, the transite template, shown in Figure 10 (p. 36), was used for support, positioning, and thermal insulation. The protocol called for using sensors with and without various fabric and fabric-underwear combinations. Figures B-3 and B-4 (pp. 49 & 51) with Tables B-3 and B-4 (pp. 48 & 50) summarize the sensor/fabric layouts.

TABLE B 1

EXPLANATION AND MEASUREMENTS OF FIGURES B-1A AND B 1B

FIGURE B-1A - Cross-section of animal template hole no. 5. Template constructed of leather and transite sheets.

Specifications:

1.	Leather sheet thickness	- 3/32"
2.	Transite sheet thickness	- 1/4"
3.	Hole diameter in upper transite sheet	- 1 13/16"
4.	Hole diameter in lower transite sheet	- 2 5/16"
5.	Calorimeter diameter	- 1 11/16"
6.	Calorimeter thickness	- 3/16"

FIGURE B-1B - Cross-section of animal template hole numbers 1, 2, 3, 4, and 6. Template constructed of leather and transite sheets.

Specifications:

1.	Leather sheet thickness	- 3/32"
2.	Transite sheet thickness	- 1/4"
3.	Hole diameter in leather, hole nos. 1, 3	- 1 9/16"
4.	Hole diameter in upper transite, hole nos. 1, 3	- 1 9/16"
5.	Hole diameter in lower transite, hole nos. 1, 3	- 2 1/16"
6.	Hole diameter in leather, hole nos. 2, 4, 6	- 2"
7.	Hole diameter in upper transite, hole nos. 2, 4, 6	- 2"
8.	Hole diameter in lower transite, hole nos., 2, 4, 6	- 2 1/2"

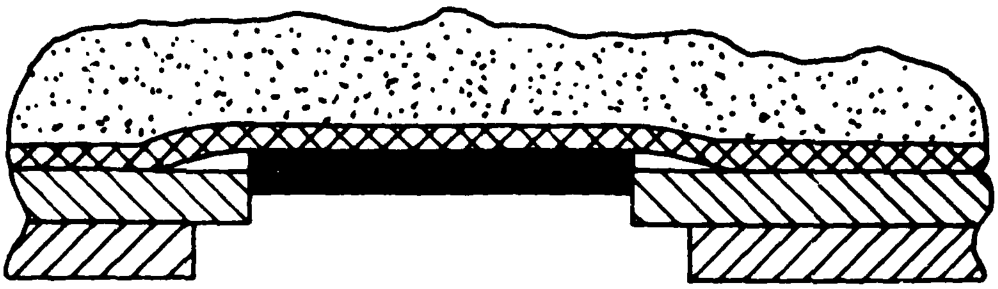


FIGURE B-1A. Cross-Section View of Animal Template.

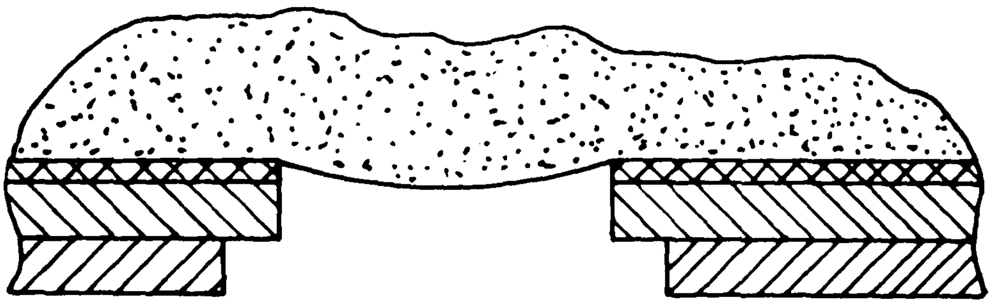
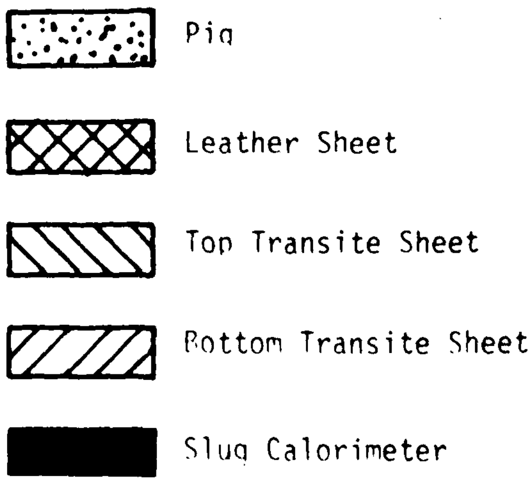


FIGURE B-1B. Cross-Section View of Animal Template.



LEGEND

TABLE B 2

EXPLANATION AND MEASUREMENTS OF FIGURES B-2A, B-2B, B-2C, AND B-2D

Cross-section views of animal template hole numbers 1, 2, 3, 4, and 6. Hole number 5 shown, FIGURE B-1A.

Specifications, all holes:

1.	Leather sheet thickness	- 3/32"
2.	Top transite sheet thickness	- 1/4"
3.	Bottom transite sheet thickness	- 1/4"

Specifications, hole numbers 1 and 3:

1.	Hole diameter in leather sheet	- 1 9/16"
2.	Hole diameter in top transite sheet	- 1 9/16"
3.	Hole diameter in bottom transite sheet	- 2 1/16"

Specifications, hole numbers 2, 4, and 6:

1.	Hole diameter in leather sheet	- 2"
2.	Hole diameter in top transite sheet	- 2"
3.	Hole diameter in bottom transite sheet	- 2 1/2"

FIGURE B-2A. Cross-section view of one layer of fabric contacting pig's skin.

FIGURE B-2B. Cross-section view of two pieces of fabric contacting pig's skin. The piece of underwear is between the pig and thermal protective fabric.

FIGURE B-2C. Cross-section view of one piece of fabric spaced away from pig by about 1/4 inch at the circumference.

FIGURE B-2D. Cross-section view of two pieces of fabric, a thermal protective outer fabric, and underwear contacting pig; outer material spaced as in FIGURE B-2C above.

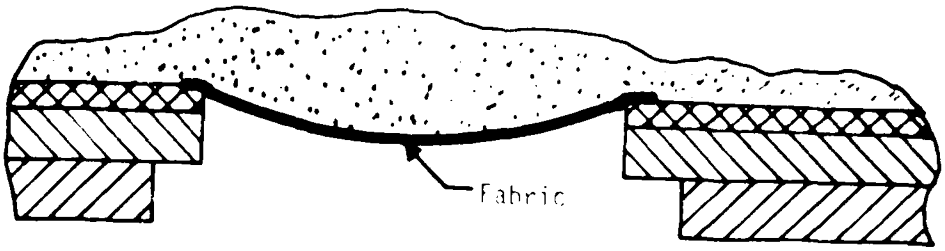


FIGURE B-2A

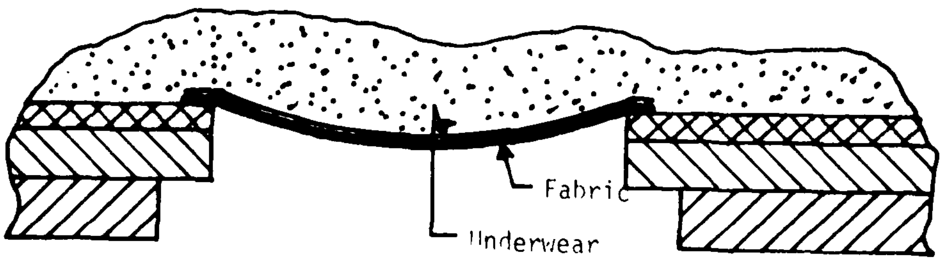


FIGURE B-2B

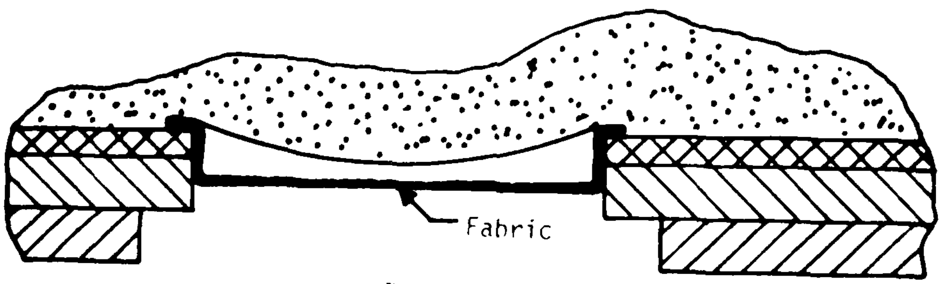


FIGURE B-2C

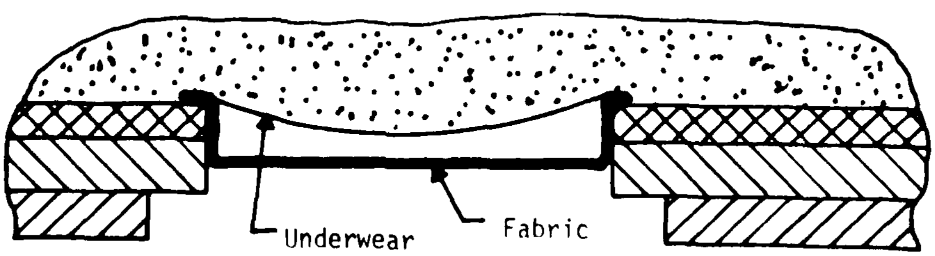
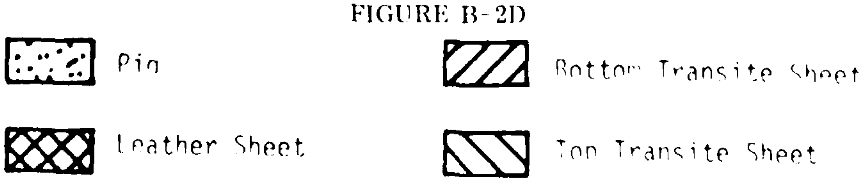


FIGURE B-2D



LEGEND

TABLE B 3

EXPLANATION OF FIGURES B-3A, B-3B, B-3C, and B-3D

FIGURE B-3A - Cross-section of sensor template hole no. 5.

1. Sensor - slug calorimeter
2. Hole diameter top transite sheet - 1 13/16"
3. Hole diameter bottom transite sheet - 2 5/16"

FIGURE B-3B - Cross-section of sensor template hole no. 2.

1. Sensor - Hy Cal calorimeter
2. Hole diameter top transite sheet - 1 1/16"
3. Hole diameter bottom transite sheet - 1 9/16"

FIGURE B-3C - Cross-section of sensor template hole nos. 1, 3, 4, and 6.

1. Sensor - Aerotherm calorimeter
2. Hole diameter in transite sheet - dependent upon position used

FIGURE B-3D - Cross-section of sensor template hole nos. 1, 3, 4, and 6.

1. Sensor - Fabric Research Laboratory calorimeter
2. Hole diameter in transite sheet - dependent upon position used

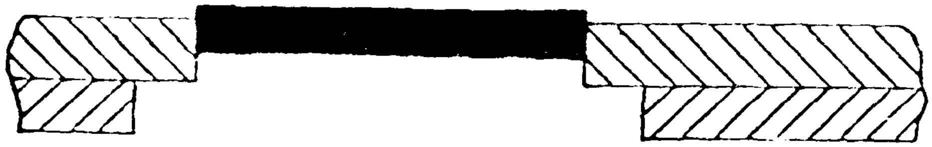


FIGURE B-3A

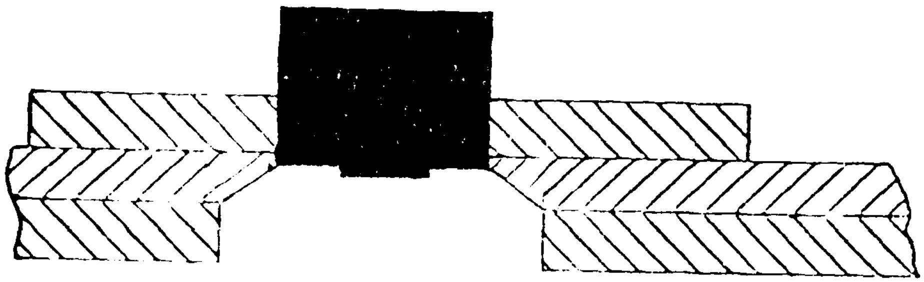


FIGURE B-3B

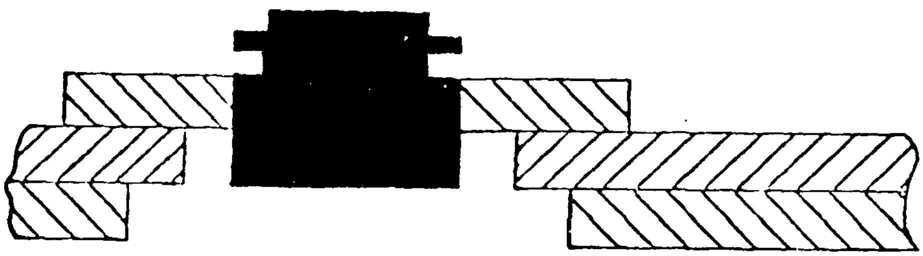


FIGURE B-3C

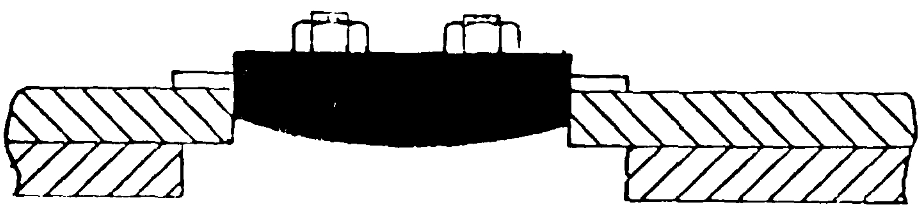
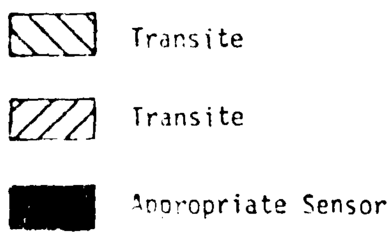


FIGURE B-3D



LEGEND

TABLE B-4

EXPLANATION OF FIGURES B-4A, B-4B, B-4C, and B-4D

Cross section of sensor template when used to evaluate the effect of fabric on sensor performance. Sensors guarded from furnace heat by one layer of thermal protective fabric. Hole diameter of transite sheet dependent upon position (See Fig. 9, p. 36).

FIGURE B-4A - Cross-section view of Aerotherm calorimeter with fabric contacting surface completely.

FIGURE B-4B - Cross-section view of Fabric Research Laboratory calorimeter with fabric contacting surface completely.

FIGURE B-4C. Cross-section view of Aerotherm calorimeter with fabric spaced away.

FIGURE B-4D. Cross-section view of Fabric Research Laboratory calorimeter with fabric spaced away.

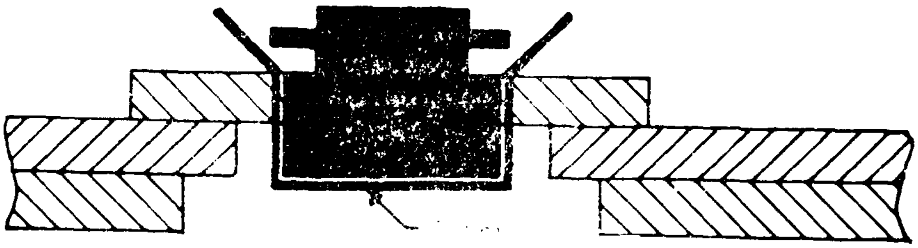


FIGURE B-4A

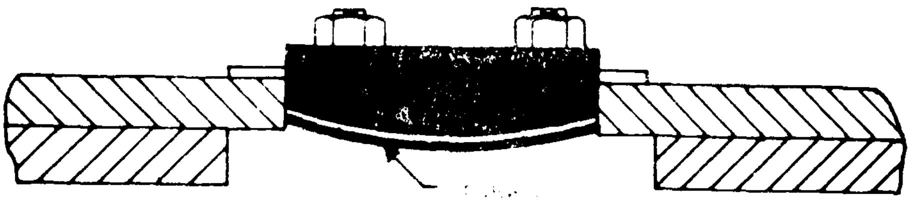


FIGURE B-4B

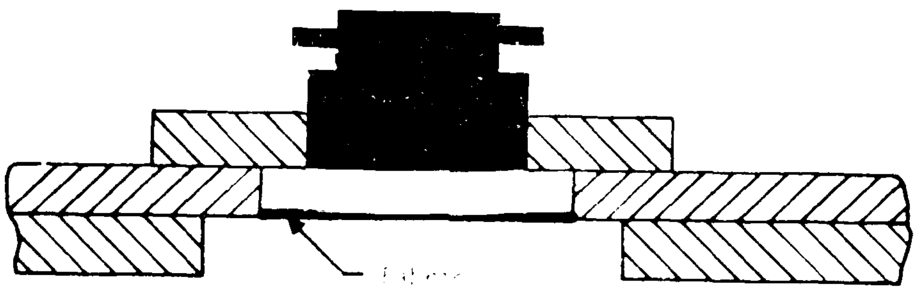


FIGURE B-4C

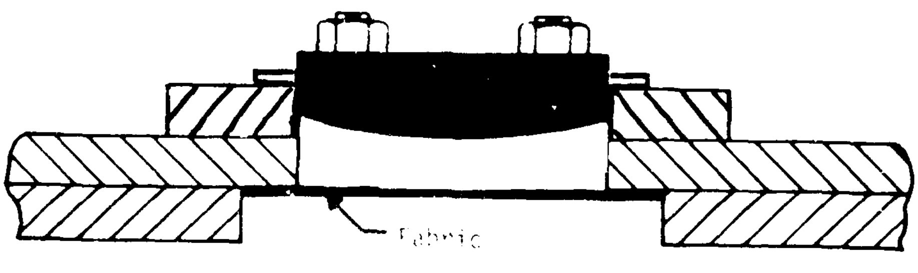


FIGURE B-4D

LEGEND

APPENDIX C

DATA ACQUISITION SYSTEM

INTRODUCTION

Block diagrams of the data acquisition and control system are shown in Figures C-1 through C-9 (pp. 57-60). As shown in Figure C-1 (p. 57), the instrumentation can be divided into three functional subsystems:

1. Digital data acquisition
2. Analog data acquisition
3. Data input and shutter control subsystem

EQUIPMENT

Aside from the instruments listed below, all instrumentation including the calibrator, exposure timer, and sequence controller were designed and fabricated at USAARL. The pneumatic shutter control system was designed and fabricated under USAARL contract at IITRI.

SENSORS

- Wall temperature thermocouple, 3/4" x 1 1/2" x 1/8" steel plate with chromel-alumel leads
- Omega chromel-alumel .015" thermocouples
- Omega copper-constantan .005" intradermal thermocouples
- Skin temperature thermocouple, styrofoam insulated copper-constantan foil
- Hy-Cal calorimeter model C1300-A-072

- Hy Cal radiometer model R-8002-B15-072
- 1 3/4" diameter x 3/16" aluminum slug calorimeter
- Calorimeters manufactured by Aerotherm Corporation and Fabric Research Laboratories

OTHER HARDWARE

- Sangamo Model 3600 magnetic tape recorder/reproducer
- Newport Model 800 digital tape printer
- Brush (Gould) Model 481 analog strip chart recorder
- Newport Model 2600 digital thermocouple indicator
- Hewlett-Packard 5326B timer/counter/DVM
- Wavetek Model 115 function generator
- Kay Model 170 ice point reference
- Nonlinear Systems series XL-2 digital multifunction meter

DIGITAL DATA ACQUISITION

The following data appear in digital form:

- Furnace wall temperature
- Hy Cal calorimeter output voltage
- Temperature of slug calorimeter
- Skin temperature

In essence, the above digital data provide real time information on available heat output from the furnace and an indication of initial pigskin temperature.

The digital data acquisition system is shown in Figure C-2 (p. 57). An amplified signal from either the Hy Cal calorimeter (heat flux from fire source) or a copper-constantan thermocouple (pigskin temperature) was monitored on a digital voltmeter to the nearest .01 millivolt. The operational amplifier is nominally set for a gain of 1×10^3.

Furnace wall temperature was sensed with a chromel-alumel thermocouple and read directly on the Newport Model 2600 digital thermocouple indicator. An ice point reference is incorporated in the instrument. Source heat flux was sensed by s slug calorimeter and recorded by the digital thermocouple indicator system.

A digital printout for both signals was provided on the Newport 800 data printer.

ANALOG DATA ACQUISITION

Output voltages from skin simulants and thermocouples were recorded as analog data on the Sangamo 3600 tape recorder for subsequent analog to digital conversion. A block diagram of an analog data acquisition system is shown in Figure C-3 (p. 58). Known EMF's were introduced at the input of each amplifier in the form of a series of calibration steps. Where necessary, limiters were used to avoid overdriving the tape recorder with the calibration signal.

To facilitate analog to digital conversion of the data, a control signal was recorded onto a separate channel. This signal is illustrated in Figure C-4 (p. 58).

CONTROL SUBSYSTEM

The control subsystem provided control commands and timing signals to the following:

1. Shutter solenoid
2. Analog tape recorder
3. Amplifier input relays
4. Calibration generator
5. Gated oscillator

The relationship of the controller and experimental elements controlled is shown in Figure C-5 (p. 59). Figure C-6 (p. 59) shows a block diagram of the experiment controller.

The shutter timer is shown in Figure C-7 (p. 60). It consisted of six individually adjustable timers connected in series. Timer #1 provided a two second delay before the shutter started to open. Timer #5 gave the command to close the shutter. This permits repetitive shutter times anywhere between 0.50 and 20.00 seconds. Following each exposure the actual shutter open time (actually the difference between the open and closing) was read on the Hewlett-Packard 5326B timer to within .01 seconds.

The output of the shutter timer drove electropneumatic valves through latching relays. This is illustrated in Figure C-8 (p. 60).

CONTROL SEQUENCE OF EXPERIMENT EVENTS

An experimental control sequence is described in the following steps:

1. Operator depresses START button.

   a. Start initial calibration phase (pre-cal) and register the appropriate voltage on the computer control channel (Level 0 to Level 1, Fig. C-4, p. 58).

   b. Calibration generator steps through calibration signals.

   c. Gated oscillator (time generator) activates.

2. Completion of final calibration level.

   a. Sensors connected to amplifier inputs.

   b. Shutter time activated.

   c. Computer control channel registers appropriate voltage (Level 1 to Level 2, Fig. C-4, p. 58).

3. Shutter timer activates shutter solenoid control.

a. Shutter opens for pre-set time.

b. Voltage appearing on computer control channel changes (Level 2 to Level 3, Fig. C-4, p. 58).

c. Shutter closes.

d. Voltage appearing on computer control channel changes (Level 3 to Level 2, Fig. C-4, p. 58).

4. Operator depresses END DATA button.

   a. Amplifier inputs switched to calibration generator.

   b. Calibration generator activated.

   c. Computer control channel voltage assumes "post-cal" level (Level 2 to Level 1, Fig. C-4, p. 58).

5. Final calibration level is completed; amplifier inputs grounded.

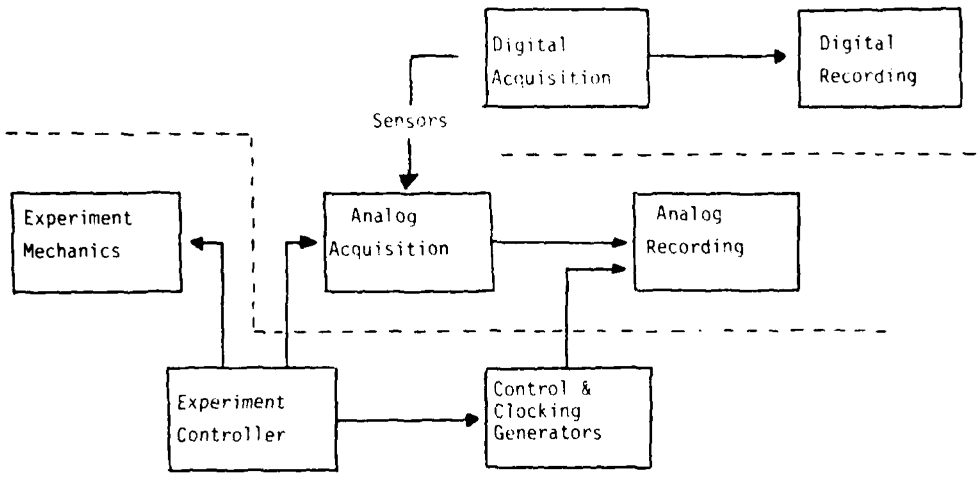


FIGURE C-1. Generalized Data Acquisition System.

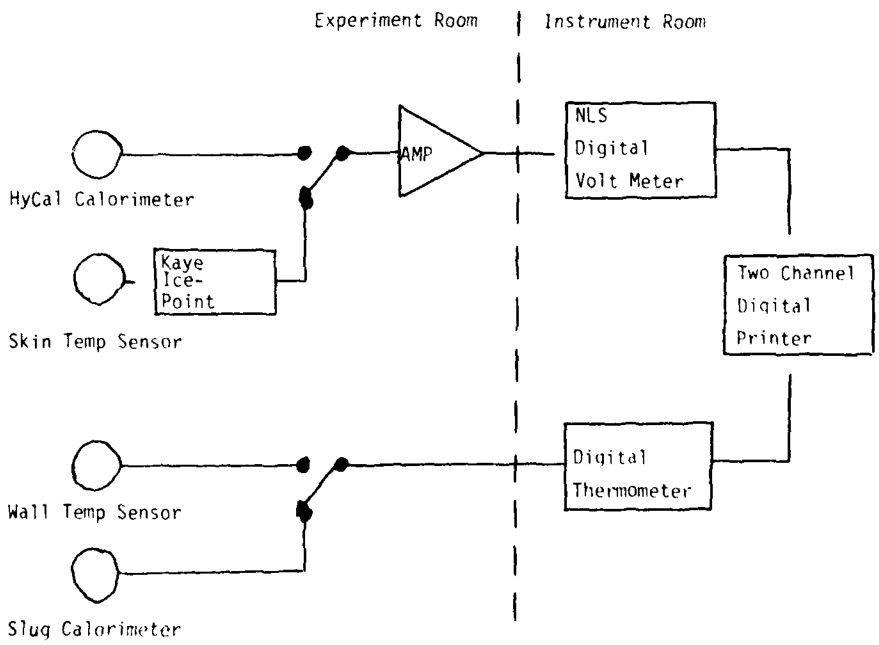


FIGURE C-2. Digital Data Acquisition System.

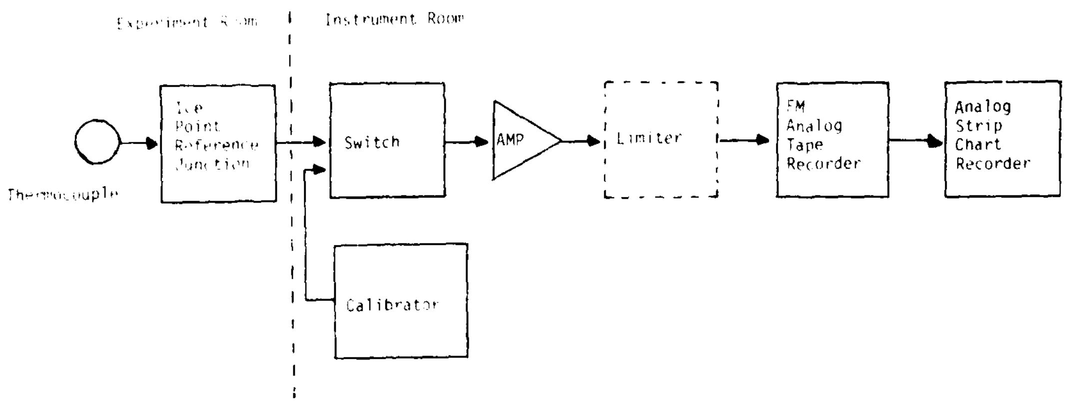


FIGURE C-3. Analog Data Acquisition System.

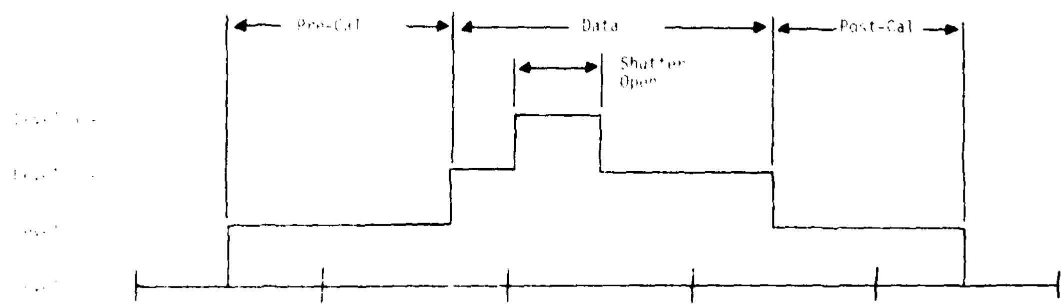


FIGURE C-4. Control Signal Amplitude vs. Time.

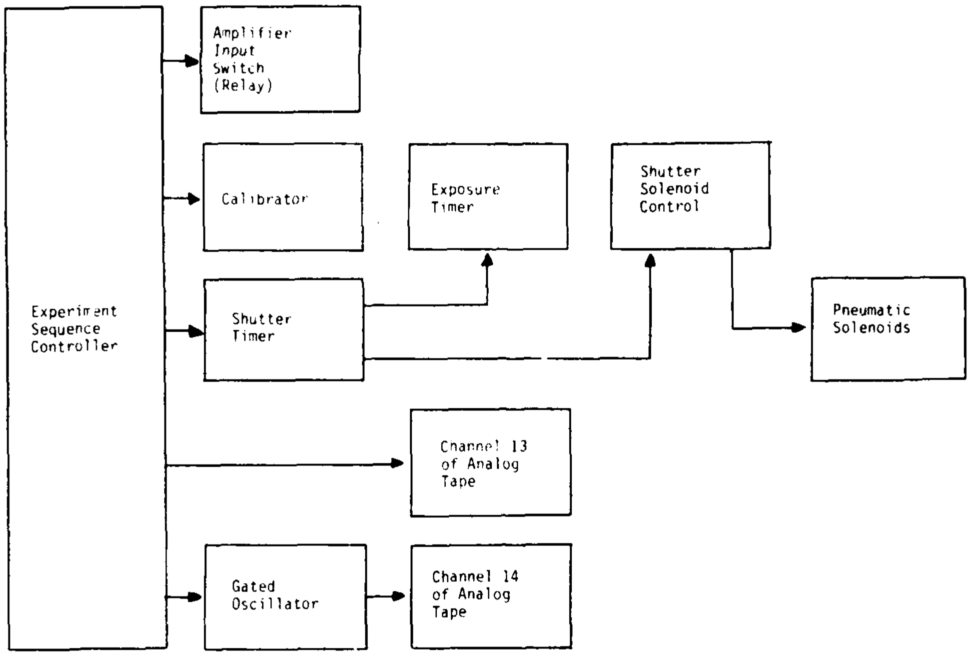


FIGURE C-5. Controller and Elements of Experiment.

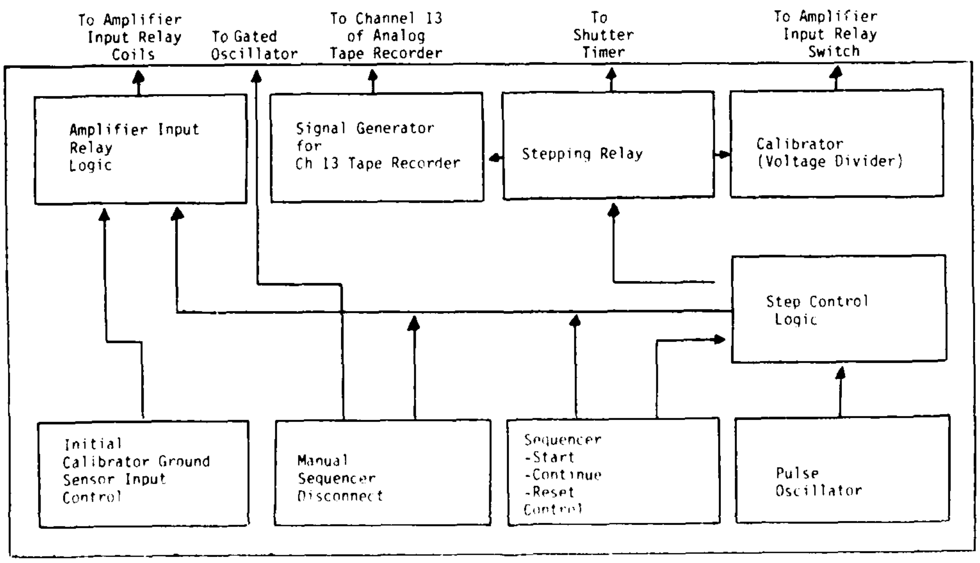


FIGURE C-6. Sequence Controller.

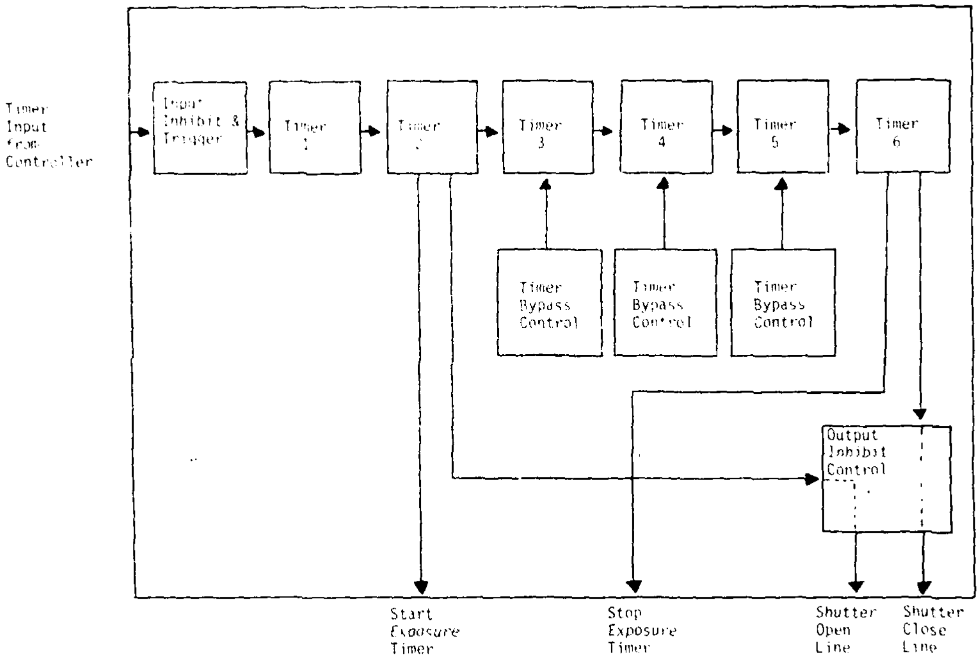


FIGURE C-7. Shutter Timer.

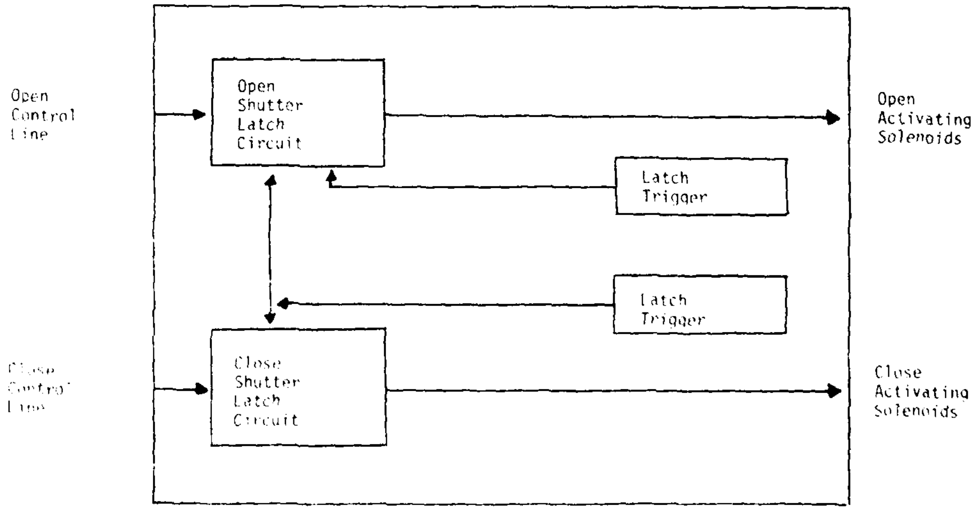


FIGURE C-8. Pneumatic Solenoid Control.

APPENDIX D

THERMAL PROJECT BIBLIOGRAPHY

THERMAL PROJECT BIBLIOGRAPHY

PAPERS

Knox, F. S. III, McCahan, G. R., Jr., and Wachtel, T. L. 1974. Use of the pig as a bioassay substrate for evaluation of thermal protective clothing and physical sensor calibration. *Aerospace Medicine.* 45(8): 933-938. (Overall method and evaluation of thermal underwear.)

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1978. Biomedical constraints on thermal protective flight clothing design: a bioengineering analysis. In: *Operational Helicopter Aviation Medicine:* Aerospace Medical Panel Specialists' Meeting, 1-5 May 1978; Ft. Rucker, AL. London: Technical Editing and Reproduction Ltd. p. 63-1--63-11. AGARD-CP-255. (Definition of worst credible environment and collection of porcine burn data base.)

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1978. How to measure the burn-preventive capability of nonflammable textiles: a comparison of the USAARL porcine bioassay technique with mathematical models. *Burns.* 5(1): 19-29. Also reprinted as USAARL Report No. 79-5. 1979. (Uses model and sensor output to predict burns.)

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1978. Mathematical models of skin burns induced by simulated postcrash fires as aids in thermal protective clothing design and selection. In: *Army Science Conference Proceedings.* Vol. II, p. 267-281, Principal Authors G thru M. (Introduces multidiscriminate and analytical models.)

Knox, F. S. III, Wachtel, T. L., and McCahan, G. R., Jr. 1979. Bioassay of thermal protection afforded by candidate flight suit fabrics. *Aviation, Space, and Environmental Medicine.* 50(10): 1023-1030. (Bioassay method (using pigs) used to evaluate four fabrics, including Nomex® and HT4.)

Knox, F. S. III, Wachtel, T. L., McCahan, G. R., Jr., and Knapp, S. C. 1979. The effect of fiber and dye degradation products (FDP) on burn wound healing. *Aviation, Space, and Environmental Medicine*. 50(10): 1007-1015. (Looks at the potential hazard associated with condensation of dyes and fiber subunits on wound healing.)

Wachtel, T. L., Knox, F. S. III, and McCahan, G. R., Jr. 1977. Methods of preparing porcine skin for bioassay of thermal injury. *Military Medicine*. 141:536-538. (Comparison of clipping vs. depilation.)

REPORTS

Albright, J., Knox, F. S. III, DuBois, D. R., and Keiser, G. M. 1971. *The testing of thermal protective clothing in a reproducible fuel fire environment, phase I report: a feasibility study*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL LR-71-3-3-2.

Albright, J. D., Knox, F. S. III, DuBois, D. R., and Keiser, G. M. 1971. *The testing of thermal protective clothing in a reproducible fuel fire environment, a feasibility study*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 71-24. (Defines postcrash fire environment and assesses the proper directions of future research.)

Knox, F. S. III. 1972. *Preliminary results, conclusions and recommendations from the evaluation of helmet flammability - DH-132 and T56-6 helmets*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL LR-72-17-3-5.

Knox, F. S. III. 1979. *VIPER exhaust burn hazard*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL LR-79-9-1-1. (Application of the model BRNSIM to assess the hazard associated with exposure to hot gases.)

Knox, F. S. III, and Bailey, R. W. 1973. *Results, conclusions and recommendations from the evaluation of helmet flammability - DH-132 and T56-6 helmets*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL LR-73-9-3-4.

Knox, F. S. III [and others]. 1971. *Engineering test of lightweight underwear of the winter flight clothing system: thermal protection.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 71-19. (First use of the USAARL bioassay method.)

Knox, F. S. III, and Nockton, R. A. 1976. *Data analysis and mathematical modeling based on U. S. Army Aeromedical Research Laboratory's experimental porcine burn - phase I data. (1 July 1975 - 30 September 1976)* Shreveport, LA: LSU School of Medicine, Department of Physiology and Biophysics. Contract DABT01 75-C-0257.

Knox, F. S. III, and Nockton, R. A. 1977. *Predictibility of burn depth: data analysis and mathematical modeling based on U. S. Army Aeromedical Research Laboratory's experimental porcine burn data. (Annual Summary Report)* Shreveport, LA: LSU School of Medicine, Department of Physiology and Biophysics. USAMRDC Contract DAMD17-77 C-7004. (Available from the Defense Documentation Center, Alexandria, VA.)

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1979. *How to measure the burn-preventive capability of nonflammable textiles: a comparison of the USAARL porcine bioassay technique with mathemetical models.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 79-5. Reprinted from *Burns: The Journal of the International Society for Burn Injuries.* 5(1):19-29, 1978.

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1978. *Mathematical models of skin burns induced by simuloted postcrash fires as aids in thermal protective clothing design and selection.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 78-15.

Knox, F. S. III, Wachtel, T. L., McCahan, G. R., Jr., and Knapp, S. C. 1978. *The effect of fiber and dye degradation products (FDP) on burn wound healing.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 78-10.

Knox, F. S. III, Wachtel, T. L., and McCahan, G. R., Jr. 1978. *Evaluation of four thermally protective fabrics using the USAARL bioassay method.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 78-9.

Knox, F. S. III [and others]. 1972. *The effect of fiber and dye degradation products (FDP) on burn wound healing*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL LR-73-4-1-1. (Reviewed by Pruitt, et al, U. S. Army Institute of Surgical Research, Ft. Sam Houston, TX 78234.)

Knox, F. S. III, Wachtel, T. L., Trevethan, W. P., and McCahan, G. R., Jr. 1978. *A porcine bioassay method for analysis of thermally protective fabrics: a histological and burn depth grading system*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 78-11. (Technique of assessing burn damage as seen on biopsy of the burn wound.)

McCahan, G. R., Jr., and Wachtel, T. L. 1972. *Anesthesia or immobilization of domestic and miniature swine - methods and some problems*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 73-6.

Wachtel, T. L., Knox, F. S. III, and McCahan, G. R., Jr. 1978. *A porcine bioassay method for analysis of thermally protective fabrics: a clinical grading system*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 78-8. (Method of grading burn severity based on external appearance.)

Wachtel, T. L., and McCahan, G. R., Jr. 1973. *A comparison of methods of preparing porcine skin for bioassay of thermal injury*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 73-9.

Wachtel, T. L., and McCahan, G. R., Jr. 1973. *Porcine burn shock - development of a reliable model and response to sodium, water, and plasma loads administered for resuscitation*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 73-12. (Further evidence for the use of the pig as a human model in burn research.)

Wachtel, T. L., McCahan, G. R., Jr., and Perez-Poveda, D. A. 1973. *Rectal temperatures of miniature and domestic swine*. Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 73-10.

Wachtel, T. L., McCahan, G. R., Jr., Watson, W., and Gorman, M. 1972. *Determining the surface areas of miniature swine and domestic swine by geometric design - a comparative study.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 73-5.

REPORTS IN FINAL DRAFT - SUBMITTED FOR PUBLICATION

Knox, F. S. III, and Nockton, R. A. 1979. *Predictability of burn depth data analysis and mathematical modeling based on U. S. Army Aeromedical Research Laboratory's experimental porcine burn data.* Shreveport, LA: LSU School of Medicine, Department of Physiology and Biophysics. Contract DAMD17-77-C-7004. 101 p.

Knox, F. S. III [and others]. 1979. *A fire simulator shutter system for testing protective fabrics and calibrating thermal sensors.* Ft. Rucker, AL: U. S. Army Aeromedical Research Laboratory. USAARL Report No. 79-4. (This is the report you are now reading.)

ABSTRACTS

Knox, F. S. III [and others]. 1973. *The use of the pig as a bioassay substrate for evaluation of thermal protective clothing and physical sensor clothing and physical sensor calibration.* American Burn Association Clinical Program. 1973 April 6-7.

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1978. *Biomedical constraints on thermal protective flight clothing design - a bioengineering analysis.* AGARD/NATO Aerospace Medical Panel Specialists' Meeting on Operational Helicopter Aviation Medicine, 1978 May 1-5, Ft. Rucker, AL.

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1978. *How to measure the burn preventive capability of nonflammable textiles - a comparison of the USAARL porcine burn assay technique with mathematical models.* 5th International Congress on Burn Injuries, 1978 June 18-22, Stockholm, Sweden.

Wachtel, T. L., and McCahan, G. R., Jr. 1973. *Porcine burn shock responses to sodium, water and plasma loads administered for resuscitation.* American Burn Association Research Program, 1973 April 6-7.

ABSTRACTS SUBMITTED

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1980. *Burn prediction model for thermally protective clothing evaluation.* Aerospace Medical Association 51st Annual Scientific Meeting; 1980 May 1-5; Anaheim, CA.

PRESENTATIONS

Knox, F. S. III. 1971. *Protective clothing for aviators.* Presented at the Third U. S. Army Aviation Accident Prevention Conference; 1971 August 18-19; Ft. Rucker, AL.

Knox, F. S. III. 1972. *Realistic evaluation of fabrics for thermal protective clothing.* Presented to the Survival and Flight Equipment Association 10th Annual Symposium; 1972 October 2-5; Phoenix, AZ.

Knox, F. S. III [and others]. 1976. *Bioassay of thermal protection afforded by candidate flight suit fabrics.* Presented at the Tenth Scientific Session of the Joint Committee on Aviation Pathology; 1976 September 6-12; Halton, England.

Knox, F. S. III [and others]. 1976. *The effect of fiber and dye degradation products (FDP) on burn wound healing.* Presented to the Joint Committee on Aviation Pathology; 1976 September 6-12; Halton, England.

Knox, F. S. III [and others]. 1973. *The use of the pig as a bioassay substrate for evaluation of thermal protective clothing and sensor calibration.* Presented at the American Burn Association 5th Annual Meeting; 1973 April 6; Dallas, TX. (16mm color, sound film, 20 minutes.) (This film shows the overall methods discussed herein.)

Knox, T. (F. S. III), and Knapp, S. C. 1975. *Testing for thermal protection.* An invited paper. 4th National Flame-Free Design Conference; 1975 March 11-13; San Diego, CA.

Knox, F. S. III, McCahan, G. R., Jr., and Wachtel, T. L. 1972. *The use of the pig as a bioassay substrate for evaluation of thermal protective clothing and physical sensor calibration.* Presented to the Eighth Scientific Sessions of the Joint Committee on Aviation Pathology; 1972 October 8-12; Colorado Springs, CO.

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1978. *Biomedical constraints of thermal protective flight clothing design: a bioengineering analysis*. Presented at the AGARD/NATO Aerospace Medical Specialists' Meeting on Operational Helicopter Aviation Medicine; 1978 May 1-5; Ft. Rucker, AL.

Knox, F. S., Wachtel, T. L., and Knapp, S. C. 1978. *How to measure the burn preventive capability of nonflammable textiles: a comparison of the USAARL porcine bioassay technique with mathematical models*. Fifth International Congress on Burn Injuries; 1978 June 18; Stockholm, Sweden.

Knox, F. S. III, Wachtel, T. L., and Knapp, S. C. 1978. *Mathematical models of skin burns induced by simulated postcrash fires as aids in thermal protective clothing design and selection*. Presented to the Army Science Conference; 1978 June 20-22; U. S. Military Academy; West Point, NY.

Wachtel, T. L. 1976. *A porcine experimental model for the study of glucagon, insulin and glucose relationships in severe burns*. Eighth Annual Meeting of American Burn Association; 1976 April 2; San Antonio, TX.

Wachtel, T. L. 1971. *Engineering test of lightweight underwear of the winter flight clothing system: thermal protection*. Eleventh Annual Joint Army-Navy Research Panel Meeting; 1971 July 21; Pensacola, FL.

Wachtel, T. L., and McCahan, G. R., Jr. 1974. *Porcine burn shock - response to sodium, water and plasma loads administered for resuscitation*. Fourteenth Annual Joint Army-Navy Aviation Medical Research Symposium; 1974 July 17; Ft. Rucker, AL.

INITIAL DISTRIBUTION

Defense Documentation Center
Alexandria, VA 22314 (12)

Director of Defense, Research and Engineering
ATTN: Assistant Director (Environmental & Life Sciences)
Washington, DC 20301 (1)

Uniformed Services University of the Health Sciences
4301 Jones Bridge Road
Bethesda, MD 20014 (1)

Commander
US Army Medical Research and Development Command
ATTN: SGRD-AJ (Mrs. Madigan)
Fort Detrick
Frederick, MD 21701 (5)

Redstone Scientific Information Center
DRDMI-TBD
US Army Missile R&D Command
Redstone Arsenal, AL 35809 (1)

US Army Yuma Proving Ground
Technical Library
Yuma, AZ 85364 (1)

US Army Aviation Engineering Flight Activity
ATTN: DAVTE-M (Technical Library)
Edwards AFB, CA 93523 (1)

US Army Combat Developments Experimentation Command
Technical Library
HQ, USACDEC
Box 22
Fort Ord, CA 93941 (1)

Aeromechanics Laboratory
US Army Research & Technology Labs
Ames Research Center, M/S 215-1
Moffett Field, CA 94035 (1)

Sixth United States Army
ATTN: SMA
Presidio of San Francisco,
California 94129 (1)

Director
Army Audiology & Speech Center
Walter Reed Army Medical Center
Forest Glen Section, Bldg 156
Washington, DC 20012 (1)

US Army Materiel Command
Harry Diamond Laboratories
Scientific & Technical Information Offices
2800 Powder Mill Road
Adelphi, MD 20783 (1)

US Army Ordnance Center & School
Library, Bldg 3071
ATTN: ATSL-DOSL
Aberdeen Proving Ground, MD 21005 (1)

US Army Environmental Hygiene Agency
Library, Bldg E2100
Aberdeen Proving Ground, MD 21010 (1)

Technical Library
Chemical Systems Laboratory
Aberdeen Proving Ground, MD 21010 (1)

US Army Materiel Systems Analysis Agency
ATTN: Reports Distribution
Aberdeen Proving Ground, MD 21005 (1)

Director
Biomedical Laboratory
Aberdeen Proving Ground, MD 21010 (1)

HQ, First United States Army
ATTN: AFKA-MD (Surgeon's Ofc)
Fort George G. Meade, MD 20755 (1)

Director
Ballistic Research Laboratory
ATTN: DRDAR-TSB-S (STINFO)
Aberdeen Proving Ground, MD 21005 (2)

US Army Research & Development Technical Support Agency
Fort Monmouth, NJ 07703 (1)

CDR/DIR
US Army Combat Surveillance & Target Acquisition Laboratory
ATTN: DELCS-D
Fort Monmouth, NJ 07703 (1)

US Army Avionics R&D Activity
ATTN: DAVAA-O
Fort Monmouth, NJ 07703 (1)

US Army White Sands Missile Range
Technical Library Division
White Sands Missile Range
New Mexico 88002 (1)

Chief
Benet Weapons Laboratory
LCWSL, USA ARRADCOM
ATTN: DRDAR-LCB-TL
Watervliet Arsenal
Watervliet, NY 12189 (1)

US Army Research & Technology Labs
Propulsion Laboratory MS 77-5
NASA Lewis Research Center
Cleveland, OH 44135 (1)

US Army Field Artillery School Library
Snow Hall, Room 16
Fort Sill, OK 73505 (1)

US Army Dugway Proving Ground
Technical Library
Bldg 5330
Dugway, UT 84022 (1)

US Army Materiel Development & Readiness Command
ATTN: DRCSG
5001 Eisenhower Avenue
Alexandria, VA 22333 (1)

US Army Foreign Science & Technology Center
ATTN: DRXST IS1
220 7th St., NE
Charlottesville, VA 22901 (1)

US Army Training & Doctrine Command
ATTN: ATCD
Fort Monroe, VA 23651 (2)

Commander
US Army Training & Doctrine Command
ATTN: Surgeon
Fort Monroe, VA 23651 (1)

US Army Research & Technology Labs
Structures Laboratory Library
NASA Langley Research Center
Mail Stop 266
Hampton, VA 23665 (1)

Commander
10th Medical Laboratory
ATTN: DEHE (Audiologist)
APO New York 09180 (1)

Commander
US Army Natick R&D Command
ATTN: Technical Librarian
Natick, MA 01760 (1)

Commander
US Army Troop Support & Aviation
Materiel Readiness Command
ATTN: DRSTS-W
St. Louis, MO 63102 (1)

Commander
US Army Aviation R&D Command
ATTN: DRDAV-E
P. O. Box 209
St. Louis, MO 63166 (1)

Director
US Army Human Engineering
Laboratory
ATTN: Technical Library
Aberdeen Proving Ground, MD
21005 (1)

Commander
US Army Aviation Research &
Development Command
ATTN: Library
P. O. Box 209
St. Louis, MO 63166 (1)

Commander
US Army Health Services Command
ATTN: Library
Fort Sam Houston, TX 78234 (1)

Commander
US Army Academy of Health Sciences
ATTN: Library
Fort Sam Houston, TX 78234 (1)

Commander
US Army Airmobility Laboratory
ATTN: Library
Fort Eustis, VA 23601 (1)

Air University Library (AUL/LSE)
Maxwell AFB, AL 36112 (1)

US Air Force Flight Test Center
Technical Library, Stop 238
Edwards AFB, CA 93523 (1)

US Air Force Armament Development
& Test Center
Technical Library
Eglin AFB, FL 32542 (1)

US Air Force Institute of Technology
(AFIT/LDE)
Bldg 640, Area B
Wright-Patterson AFB, OH 45433 (1)

US Air Force Aerospace Medical
Division
School of Aerospace Medicine
Aeromedical Library/TSK-4
Brooks AFB, TX 78235 (1)

Director of Professional Services
Office of The Surgeon General
Department of the Air Force
Washington, DC 20314 (1)

Human Engineering Division
6570th Aerospace Medical Research
Laboratory
ATTN: Technical Librarian
Wright-Patterson AFB, OH 45413 (1)

US Navy
Naval Weapons Center
Technical Library Division
Code 2333
China Lake, CA 93555 (1)

US Navy
Naval Aerospace Medical Institute
Library
Bldg 1953, Code 012
Pensacola, FL 32508 (1)

US Navy
Naval Submarine Medical Research
Lab
Medical Library, Naval Submarine
Base
Box 900
Groton, CT 06340 (1)

Director
Naval Biosciences Laboratory
Naval Supply Center, Bldg 844
Oakland, CA 94625 (1)

Naval Air Systems Command
Technical Library AIR 950D
Rm 278 Jefferson Plaza II
Department of the Navy
Washington, DC 20361

US Navy
Naval Research Laboratory Library
Code 1433
Washington, DC 20375 (1)

US Navy
Naval Air Development Center
Technical Information Division
Technical Support Department
Warminster, PA 18974 (1)

Human Factors Engineering Division
Aircraft & Crew Systems Technology
Directorate
Naval Air Development Center
Warminster, PA 18974 (1)

US Navy
Naval Research Laboratory Library
Shock & Vibration Information Center
Code 8404
Washington, DC 20375 (1)

Director of Biological & Medical
Sciences Division
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217 (1)

Commanding Officer
Naval Medical R&D Command
National Naval Medical Center
Bethesda, MD 20014 (1)

Commander
Naval Aeromedical Research
Laboratory Detachment
P. O. Box 29407
Michoud Station
New Orleans, LA 70129 (1)

Federal Aviation Administration
Office of Aviation Medicine
Civil Aeromedical Institute
ATTN: Library
Oklahoma City, OK 73101 (1)

Department of Defence
R.A.N. Research Laboratory
P. O. Box 706
Darlinghurst, N.S.W. 2010
Australia (1)

Canadian Society of Avn Med
c/o Academy of Medicine, Toronto
ATTN: Ms. Carmen King
288 Bloor Street West
Toronto, Ontario
MS5 1V8 (1)

DCIEM/SOAM
MAJ J. Soutendam (Ret.)
1133 Sheppard Avenue West
P. O. Box 2000
Downsview, Ontario
M3M 3B9 (1)

Staff Officer, Aerospace Medicine
RAF Staff
British Embassy
3100 Massachusetts Avenue, N.W.
Washington, DC 20008 (1)

FORT RUCKER DISTRIBUTION

Commander
US Army Aviation Center and
Fort Rucker
ATTN: ATZQ-CDR
Bldg 114 (1)

Commander
US Army Aviation Center and
Fort Rucker
ATTN: ATZQ-T-ATL
Bldg 5907 (1)

Chief
US Army Research Institute Field
Unit
Bldg 501 (1)

Director
Directorate of Combat Developments
Bldg 507 (1)

Commander
US Army Aeromedical Center
Bldg 301 (3)

Commander
US Army Safety Center
Bldg 4905 (1)

Director
Directorate of Training Developments
Bldg 502 (1)

President
US Army Aviation Board
Cairns AAF. Bldg 501AB (1)

Commander
US Army Aviation Development Test
Activity
Cairns AAF, Bldg 30601 (1)